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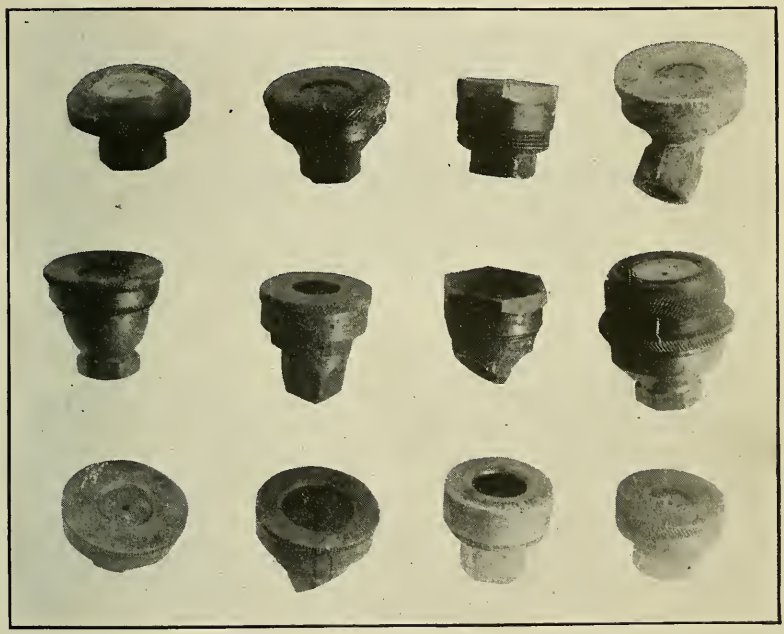
Bulletin 169 January, 1919

West Virginia University
Agricultural Experiment Station
MORGANTOWN

DEPARTMENT OF HORTICULTURE

A Study of the Factors Governing the Efficiency of Distribution and Rate of Discharge of Spray Nozzles

TECHNICAL BULLETIN



DISC NOZZLES

Top Row (left to right): Atomic, New Eclipse, Whirlpool, Excelall.
Middle Row: Tiger Strainer, Fog, Bean Mist, Nonclog Atomic.
Lower Row: Friend Regular, Friend Angle, Scientific, Mistry Jr.

BY

H. L. CRANE

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A Study of the Factors Governing the Efficiency of Distribution and Rate of Discharge of Spray Nozzles

By H. L. CRANE *

No one can apply spray materials properly unless an efficient nozzle is used. The pump and other parts of the spraying equipment may be the very best that can be procured, but by using a poor nozzle or one not adapted to the particular work being done, the quality of the spraying will be no better than the nozzle. In fact, there is no other part of the spraying equipment so important as the spray nozzle.

The efficient nozzle must combine many features. It should throw a very fine mist of uniform density. It should be simple in construction, light, durable, not easily clogged, and have no projecting parts to catch on limbs. The angle of the spray should be as wide as possible consistent with good carrying power. The economical nozzle must combine with its fine mist and even distribution a capacity large enough to insure rapidity in spraying. In many cases the manufacturers of spray nozzles have provided for the latter but at the expense of the former. Many nozzles now on the market are of such large capacity that is impossible for any one to apply the spray material evenly over a given surface without "drenching" the tree and with consequent waste.

THE BEST SPRAY

Beach, Clark, and Taylor [1] of the New York Agricultural Experiment Station, in discussing what is the most desirable spray and how to obtain it, say, "In applying Bordeaux mixture or other fungicides to any foliage it is evident that perfect work is done when the spray covers the leaf surface most completely and permanently. The same is true of spraying with arsenical insecticides or other insecticides which are applied to the leaf for the purpose of killing insects by poisoning their food. Experience shows that with liquid preparations this may be best accomplished when the liquid is broken into so fine a spray that it will rest upon the leaf in mist-like particles and dry in that position. * * * * Not only may a much better spray be applied with a perfect mist than with a coarse spray, but it may also be applied with a much less expense of time and material." If this ideal could be attained it would be perfect spraying.

* The writer wishes to express his thanks to the companies handling spray machinery who so kindly furnished sample nozzles for testing, and also to Professor W. H. Alderman of the College of Agriculture for his suggestions and criticisms.

[1] Beach, S. A., Clark, V. A., and Taylor, O. M., Spray Mixtures and Spray Machinery—New York Agr. Exp. Sta. Bul. 243 (1903) pp. 342-344.

DRIVING SPRAY FOR CODLING MOTH

In the early history of spraying for the codling moth, when it became known that from 60 to 80 percent of the larvae entered through the calyx end of the apple, horticulturists and entomologists recommended that a coarse material be used, so that it could be driven into the calyx cup. Sanderson [2] says, "Upon hatching, the young larva usually feeds a little on the tender parts of the leaves before it crawls to the nearest apple, which is probably eight or ten inches distant." From this statement we would conclude that the proper place to be sure to get the poison evenly spread would be on the leaves, and that the larvae may be poisoned before going to the apple. Sanderson [3] continues, "In the West great emphasis has recently been placed upon using a coarse spray with a high pressure, 100 to 250 pounds, which will drive the spray through the bases of the stamens into the lower calyx cavities and, though excellent results are undoubtedly secured in this way, experiments in the East indicate that a mist spray is equally effective if thoroughly applied, whether the lower calyx cavities are reached, or not."

Felt [4] reports an experiment made to test the efficiency of a coarse driving spray as compared with a fine mist spray. He concludes that the results obtained seem, so far as the Hudson River section is concerned, to justify the belief that one thorough spraying with a Vermorel nozzle within ten days after the blossoms fall will result in protecting a very large percentage of the fruit from codling moth injury.

Gossard [5] of the Ohio Experiment Station, in the results of his experiments to determine what spray should be used for codling moth control, gives the following table:

KIND OF NOZZLE	Percent Sound	Percent Wormy	Percent Damaged by Curculio
Average Record With Coarse Nozzles___	98.68	.78	.54
Average Record With Fine Nozzles_____	98.58	.79	.35

In summing up he says, "There is practically no difference in these results, and when it is remembered that the cost of materials is increased about 50 percent through waste caused by the larger nozzles, it is certainly not advisable to use them."

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[2] and [3] Sanderson, E. D., Insect Pests of Farm, Garden, and Orchard—John Wiley & Sons, New York, pp. 226 and 629 respectively.

[4] Felt, E. P., Spraying for the Codling Moth, Proceedings of the 22nd Annual Meeting of the American Association of Economic Entomologists—Journal of Economic Entomology, Vol. 3, No. 2 (1910), pp. 172-176.

[5] Gossard, H. A., Spraying for the Codling Worm—Ohio Agr. Exp. Sta. Bul. 191 (1908).

Dusting experiments [6] conducted during the past five years have shown that so far as biting insect pests are concerned they can be controlled as well, if not better, with dust as with liquid sprays. The foregoing statement seems to indicate very forcibly that if sprays were applied in an extremely fine mist evenly over the leaf area of the tree the results in codling moth control would be as good or better than could be obtained by using a driving spray, and at much less cost for time and materials. When the fungicidal value of the codling moth spray is considered we are again impressed with the advantage and importance of a fine mist.

SPRAY FOR FUNGOUS DISEASES

Even though very little experimental evidence can be found on the subject of coarse vs. fine mist spraying for controlling fungous diseases, it seems to be an established fact that the finer the mist, the better the spray.

Wallace [7] says in speaking of coarse spraying and drenching, "If the nozzle is held long in one position and throws a coarse spray, drenching certain branches, there is liable to be injury, whether the solution is weak or strong. A 1-50 solution applied in this way is more liable to burn than a 1-30 properly applied. The evidences of this are to be found in almost any orchard where certain limbs have been drenched. The solution collects in drops on the foliage and burns as the drops concentrate. * * * * The coating of the spray should consist of very fine drops evenly distributed over the entire surface. If the application is too heavy, these drops collect at the tips and around the margins of the leaves and as they dry the solution becomes more concentrated and burns." This statement of the case is in strict accordance with the writer's observations in a number of cases.

WASTE OF MATERIALS IN SPRAYING

In the application of spray materials there is always a very great waste. This waste may be due to spilling, leaks, dripping of the nozzle, use of a nozzle not adapted to the work, or one having such a large discharge that it is impossible to cover evenly the area sprayed. A very large part of this waste could be saved by having all connections tight and by using the proper nozzle. There will always be a considerable waste of materials in spraying that can not be avoided, but by changing the present methods of spraying at least 50 percent of the waste can be saved.

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[6] Blodgett, F. M., Experiments in the Dusting and Spraying of Apples—Cornell University Agr. Exp. Sta. Bul. 340 (1914).
[6] Reddick, Donald and Crosby, C. A., Further Experiments in the Dusting and Spraying of Apples—Cornell University Agr. Exp. Sta. Bul. 354 (1915).
[6] ———————, Dusting and Spraying Experiments with Apples—Cornell University Agr. Exp. Sta. Bul. 369 (1916).
[7] Wallace, Everett, Spray Injury Induced by Lime-Sulphur Preparations—Cornell University Agr. Exp. Sta. Bul. 288 (1910).

REVIEW OF LITERATURE

Booth [8] while at Missouri Agricultural Experiment Station made a study of about thirty different kinds of nozzles to determine height of spray or distance which the spray could be thrown perpendicularly with various pressures; width, shape and distribution of spray from the most efficient nozzles; size of drops; the discharge of each nozzle for a given time; and liability of the nozzle to clog and drip. He also studied the durability and method of attachment of the nozzles. He found it practically impossible to determine the shape of the most desirable spray. "It would seem that the prime essential is to secure a spray such that when passed at a uniform rate of speed over any surface it will cover every part touched with a film of liquid of equal thickness." In studying the discharge of the different nozzles, they were made to throw a spray into galvanized iron boxes six inches square, which were placed closely side by side. The discharge in each case was then measured and the distribution of the spray as well as the shape of the spray was determined.

To determine the size of the drops made by the different nozzles, a logwood ink was sprayed against blank paper placed at the best distance for each nozzle. The papers were then photographed. In regard to the size of the drops he says, "The most finely divided spray is not always the best. A fog-like or mist spray is utterly uncontrollable in even a very moderate breeze and it will not force its way into the interior of a heavy foliage."

In determining the amount of discharge, Booth used thirty pounds pressure and the discharge was caught in the galvanized iron boxes used for determining the distribution of the spray. His conclusion was that a general-purpose nozzle did not at that time exist.

In 1907 and 1908, Faurot [9] tested several spray nozzles in regard to the shape of the spray thrown and the size of the drops of the spray. He used large panes of glass on which a solution of lime was sprayed. After drying, photographs were made. His results show that a different sized orifice in the nozzles may be the governing factor in the size of the drops discharged: the larger the orifice, the larger the drops.

Some time later, Riley of Cornell University designed and built a machine called the "sprayograph" for testing the distribution efficiency of spray nozzles. With this machine a large number of nozzles was tested, but unfortunately the results remain unpublished.

R. D. Anthony tested several nozzles for the American Steel and Wire Company. He obtained the discharge per minute of the various nozzles, measured the angle of spray, and made records of the fineness and distribution of the spray. Unfortunately his results also remain unpublished. In a letter to the writer he said, in regard to some of the

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[8] Booth, N. O., A Test of Spray Nozzles—Missouri Agr. Exp. Sta. Bul. 50 (1900).
[9] Faurot, F. W., Spraying Machinery—Missouri Fruit Exp. Sta. Bul. 20 (1908).

results obtained, "We found a wide variation in the minimum pressure at which different nozzles would give a satisfactory spray; also a very decided difference in the amount of discharge of the different nozzles at the same pressure. We found that an increase in the opening in the discharge disc increased the amount of discharge and decreased the fineness of the spray." Later Anthony published a graph [10] showing the rate of discharge from two nozzles having different sized orifices. This graph shows that at low pressures the quantity of liquid discharged by a nozzle increases rapidly with an increase in pressure, but at higher pressures the increase in discharge grows less as the pressure becomes greater. As the pressure increases, the size of the spray particles decreases.

Goodwin [11] of the Ohio Agricultural Experiment Station, made a careful study of the distribution and rate of discharge of spray nozzles. In his work he used a modification of the Cornell sprayograph (about the same as used by the writer and described later) in recording his results. Tests were made of about 60 different nozzles which included representatives of every type made. He found that many nozzles throwing a hollow cone-shaped spray would throw the bulk of the spray in one-half of the circle, and stated that in the case of the disc type of nozzle this could be prevented by increasing the number of supply holes in the directing disc. He found that the angle of the spray may be changed by increasing the depth of the eddy-chamber. The size of the orifice was found to have much to do with the capacity of the nozzle but was not an absolute index. The size, shape, angle, and number of supply holes in the directing disc were found to affect the spray obtained, but in what way was not stated. Lack of care in machining the various parts of the nozzles was found to be responsible for many of the discrepancies noted in the nozzles tested. In summing up his work he said, "The maximum efficiency in the disc nozzles is to be found in those which most nearly give a solid circle of spray. Likewise in the variable disc types, the best patterns will be found in those which are capable of most nearly making a perfect ring of spray, though of course such nozzles are also designed to grade their discharge from the perfect ring through the hollow cone to the long driving stream. A few of the true Vermorel nozzles gave well distributed rings of spray. Most of the modified Vermorel nozzles throw the bulk of the spray in one-half of the circle, there being only one exception and this one gives a narrow even ring of spray. The cap nozzles were, with one exception, superior to most of the Vermorels, both in the distribution of the spray and in capacity. Cyclone nozzles were of little value, unless used in clusters." Capacity tests were made at 100 and 200 pounds pressure.

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[10] Bailey, L. H., Standard Encyclopedia of Horticulture, Vol. 4, pp. 1958-1959, Article by R. D. Anthony.

[11] Goodwin, W. H., Spraying Machinery and Accessories—Ohio Agr. Exp. Sta. Bul. 248 (1912).

In 1912, Hewitt [12] of the Arkansas Agricultural Experiment Station made a study of the disc type of spray nozzles throwing some light on the distribution and rate of discharge of these nozzles as well as the principles underlying their construction. He made a large experimental nozzle in such a way that it could be adjusted so as to increase the depth and the width of the eddy-chamber, while the size of the orifice was changed by using different discs. Several commercial nozzles were tested in addition to this one. In order to ascertain the distribution of the spray as well as the amount of discharge, six galvanized boxes were arranged in a square and the discharge of the nozzles was run into these boxes for one minute; the liquid in each was then measured. To determine the distribution of the spray discharged the principle of a focal plane shutter was used.

In speaking of the eddy-chamber, he says, "In general an increase in the depth of the eddy-chamber gave a narrower cone of spray, but if the eddy-chamber became too deep in proportion to its diameter and the size of the hole in the disc, the spray was distributed irregularly; that is, it would be heavy on one side and light on the other and would come unevenly or in spurts." The width of the eddy-chamber was found to exert an influence on the angle of spray discharged. The narrower the eddy-chamber, the narrower the angle; the wider the eddy-chamber, the wider the angle of spray. He recommended a nozzle having an eddy-chamber three-fourths of an inch wide, as a wider one gave a coarse, widely scattered spray. A thick disc was found to make the walls of the cone thinner but had no effect on the angle of the spray, although the drops were somewhat larger.

The total amount of spray discharged was found to vary with two things: "An increase in the depth of the eddy-chamber gave a larger total amount, and an increase in the diameter of the hole in the disc gave a larger total amount." His conclusions are that a nozzle delivering three to four quarts per minute is sufficient under ordinary conditions, and he recommends an aperture of five sixty-fourths of an inch, with an eddy-chamber one-eighth of an inch deep. Changing the diameter of the eddy-chamber had no appreciable effect on the amount of discharge.

Woodworth [13] of the California Agricultural Experiment Station employed a new principle in nozzle construction which produced a flat spray with the qualities of the eddy-chamber type. In describing how this was accomplished and how the spray was formed, he says. "Hitherto all flat sprays have been of lenticular section, breaking up into fine mist on the sides and into drops in the center. It was ob-

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[12] Hewitt, J. Lee, Spraying Investigations for 1912—Arkansas Agr. Exp. Sta. Bul. 114 (1913).

[13] Woodworth, C. W., A New Spray Nozzle—Jour. of Agr. Research, Vol. V (March 20, 1916), pp. 1177-1188.

served that the flat spray produced by two impinging streams was at right angles to the original plane of motion of the two streams, but when the streams failed to meet squarely the plane was shifted and could, in fact, be moved through an arc of 180° with a very great change in the distribution of the water currents. It requires only a slight angular deviation to decrease very perceptibly the coarseness of the central drops, producing greater uniformity, and a position can be reached in which the coarsest drops are on the edge, those in the center therefore being the finest."

The principle finally discovered was that when two streams meet across half their section the resulting sheet of spray will be of practically uniform thickness throughout, occupying a plane of 45° from the plane of the streams and finally breaking up into drops of great fineness and uniformity.

He says this nozzle may be made by using "any form of two-stream nozzle, like that known as the Calla, or Lily, nozzle. This nozzle can be quickly converted into one of the new type by the use of a reamer by slightly enlarging the two apertures on opposite sides by working the instrument obliquely to the surface of the nozzle and trying it from time to time until the spray sheet stands at 45°."

Pierre Larue [14] in "Revue de Viticulture" reviews the work of the School of "Arboriculture of Newstadt," bei Haardt, in which a study of the distribution of the spray particles alone was made. The method of recording results was by using a large wooden screen suspended from a post, which screen was allowed to swing like a pendulum, its speed at three points representing the maximum, the average, and the minimum gait of a man walking and spraying. The nozzle was so fixed that it was held firmly in place at a predetermined distance from the screen. The pressure used was two atmospheres under control of a manometer. The screen was covered with an unsized paper soaked with a solution of blue sulphate of iron. For their spray material a solution of potassium ferrocyanide was used. The nozzles were tested at different distances from the screen ranging from 10 centimeters to 1.2 meters.

The drops on the recording paper were divided into large, medium, and fine. In order to save counting all of the drops on the entire sheet, a section was marked off and the drops in this counted.

The results are, in the main, as follows: Higher pressures with some of the nozzles should be used. A suitable breaking up of the spray was not obtained at a distance less than 50 centimeters from the screen. An orifice is recommended having a diameter of from 1.5 mm. to 2 mm. and it is also recommended that the eddy-chamber of the nozzle be widened so as to widen out the cone of spray.

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[14] Larue, Pierre, Expiriences de Pulverisation—Revue de Viticulture, Vol. 37, No. 967, (June 1912), pp. 879-881.

HISTORY OF THE DEVELOPMENT OF SPRAY NOZZLES

Like the history of the development of all agricultural machinery, the progress with reference to spray nozzles has been fairly rapid, even though many obstacles have been met from time to time. Soon after some inventor would make a nozzle that would, from all indications, apply the various spray materials in an almost ideal way, great changes would occur in the materials used which would necessitate as great changes in the nozzles which were to apply the material. Thus, the ingenuity of the inventor has been taxed on an interesting and important problem. Even though insects and fungous diseases had been combated for many years by numerous materials of various kinds, Lodeman [15], writing in 1896, describes what he considers an ideal spray nozzle as follows, "The best spray nozzle, so far as efficiency, simplicity, and cheapness are concerned, is the end of a hose and a man's thumb. Unfortunately the thumb gets sore and tired and operations must be suspended to wait for repairs. It is the nearest approach to the ideal nozzle yet devised, if it were only more practicable. It will do all a good nozzle should do. It throws a fine mist-like spray, one that will 'float in the air like a fog' or the particles of water may instantly be made coarser, and the water thus carried to a greater distance; or still coarser and the water leaves the hose in the form of a solid stream. These changes all take place instantly (after a little practice) and it makes no difference whether the parts to be sprayed are a few inches or many feet away. This nozzle never clogs, but is cleaned automatically, and as quickly as the character of the spray is varied. The fact it possesses all the desirable qualities of our ideal spray nozzle, except durability, and for this one must turn to the metals for aid." From the description, we can readily see even at that late date the inventors had not been able to meet the demands made upon them.

The first nozzles used in spraying were those throwing a solid stream, the outlet orifices being circular (as in a fire nozzle). These were used until 1858, when Rumsey and Company advertised a new nozzle called the "Fantail." This nozzle consisted of a flat spreading tip having a long narrow opening and the material was discharged in the shape of a fan, from which the nozzle got its name. The earlier forms were made by hammering a nozzle designed to throw a circular solid stream in such a manner that the opening was long and narrow instead of circular.

About the year 1875 a modification of the circular solid stream nozzles came into use. These nozzles were known as the graduating spray nozzles because of the fact that the character of the spray discharged could be varied from a solid stream to that of a fine spray, by introducing a pointed piece of metal into the outlet orifice. This pointed piece entered the orifice from the inner side, and the farther

[15] Lodeman, E. G., Spraying of Plants—MacMillan Company, New York.

it was pushed into the opening the finer became the spray. A good example of this type is the nozzle that is now commonly used in sprinkling lawns and gardens.

At about this time a new idea in forming a spray was conceived by placing some obstruction over or just beyond the outlet orifice to prevent the free discharge of the material. This obstruction was generally a long broad piece of metal and the spray was discharged against it at a slight angle which caused the material to spread over it and in this way a coarse fan-shaped spray was produced. The "Diffuser" nozzle was the first nozzle of this kind sold.

In 1878, when a patent was granted the Belknap Company on a nozzle known as the "Boss," a new modification of the solid stream nozzle came into use. This nozzle had two outlet orifices and the stream was directed into one or the other of them by means of a hollow stopcock which was made in such a shape that it partly or entirely closed one or both of the openings. The shape of the spray and the amount of discharge could be readily varied by turning the stopcock. The "Eureka," Masson, Bordeaux (Eastern and Western), and Clipper [16] are modifications of this nozzle, the last three mentioned being in common use today.

During the summer of 1880 William S. Barnard conceived the idea of making the material whirl in a circular chamber before entering the outlet orifice. The whirling motion of the material so exaggerates the angle of discharge and this with the centrifugal force created by the whirling material causes it to be broken up into fine particles and to be distributed in the shape of a hollow cone. The nozzle made by him may be described by saying that it was like the cyclone nozzles which are still in use on bucket and knapsack sprayers. The idea set forth in this nozzle contained the basic principles involved in the disc type of nozzles which are so popular now, and from which they were developed.

"Dr. C. V. Riley [15] visited France in 1884 and in an address delivered June 30th to the Societe Centrale d' Agriculture de 1' Hercault he mentioned Barnard's nozzle, and this no doubt hastened its adoption in that country." The main objection to this nozzle was that it became clogged, but it was highly recommended by the various experiment stations from 1885 to 1905 as one of the very best nozzles. It soon attracted the attention of French manufacturers; V. Vermorel, Villefranche (Rhone), was perhaps the first to manufacture this nozzle. During 1886 and 1887 Vermorel added the disgorging pin that would clean the outlet orifice should it become clogged. In 1889 and 1890 he

[16] Patented May 13, 1902 by the Bean Spray Pump Company. The projecting parts or lips of this nozzle are so curved that all parts of the material travel the same distance and meet the same resistance, thus giving a more evenly distributed spray. The original patent was allowed October 19, 1886 and contained practically all of the features of the Bordeaux nozzle of today. Credit is due John Bean of Los Gatos for first making the Bordeaux nozzle which is so popular in the West today.—From letter to author, April, 1916.

made some other minor changes and his improved form became known as the "Vermorel." This nozzle is still used practically as it was then for small spray outfits and in clusters on power sprayers.

The Nixon Nozzle and Machine Company, Dayton, Ohio, in 1884 secured a patent on a nozzle known as the "Climax" or "Nixon." This nozzle was another modification of the "Diffuser" nozzle. The discharge from the outlet orifice of this nozzle was thrown as a solid stream against a piece of wire mesh, where it was broken up into a spray varying in character with the size of the meshes. These nozzles were highly recommended by experiment stations until as late as 1895, but since then have disappeared from the market.

Little or nothing was done to improve the solid stream nozzles until 1889, when the Bean Spray Pump Company secured a patent on a nozzle known as the "New Bean." The advantage of this nozzle lay in the fact that the width of the opening could be adjusted by means of a screw. In 1890 Bailey [17] published a description of a device by means of which the end of a hose could be contracted so as to produce a fan-shaped spray. The size of the opening could be varied at the will of the operator, and in case of clogging the hose could be opened to its fullest extent.

In the year 1890 another modification of the "Diffuser" nozzle was made. Woodin & Little of San Francisco seeing a great demand for some spray nozzles on the Pacific coast manufactured a new nozzle which they called the "San Jose," a name derived from the fact that it was mostly used in the combating of San Jose scale. This nozzle consisted of a cap in which was a tin or rubber disc having a long narrow slit thus giving the discharge from the nozzle a fan-shaped spray. The rubber discs were used in applying the heavy materials (lime-sulphur and salt) that were used as insecticides at that time. In case of clogging the particles would close the orifice, and thus the pressure would be increased and the rubber disc would give way and let the large particles go free. Woodin & Little [18] say, "At that time (1890) there were very few nozzles of any description here on the Coast and this nozzle was used for all kinds of spraying. * * * * A disc with opening cut in the same was made to suit the kind of spray material used. While we owned the patent on this nozzle, we failed to have it registered and consequently in later years various other companies manufacturing this class of goods started in to manufacture this nozzle. This nozzle is used to some extent on the Pacific Coast today."

Two years later (1892) a nozzle named after its inventor McGowen [19] was offered for sale. The McGowen nozzle was developed from ideas received from the hose-nozzle designed by L. H. Bailey in 1890. "In this nozzle the opening is formed by two pieces of metal

[17] Bailey, L. H., Cornell University Agr. Exp. Sta. Bul. 18 (1890).
[18] Letter from Woodin & Little to author, March 24, 1916.
[19] McGowen, John C., Ithaca, N. Y., A New Nozzle—American Gardening, Vol. XIV (May 1893), p. 269.

which remain in contact when not in use. One piece is movable and is in the form of a piston which moves backward and forward in a cylinder placed at right angles to the main shaft. As the pressure in the shaft increases the size of the opening enlarges, and in this manner any obstruction which may become lodged at the outlet orifice will cause an increase of pressure which forces the piston back, thus allowing the passage of the obstruction." This nozzle was recommended by agricultural experiment stations and others from 1895 to 1905 as excelled by none except the Vermorel, but it has now gone out of use.

It was 1895 before any marked changes in nozzle construction were made, but at that time a new nozzle, "The Ball" [15] was extensively advertised. "At the end of a hose is fastened a hollow conical piece of metal in which a light ball loosely rests. As the liquid is forced against the ball the latter is not ejected but remains to break up the liquid into a fairly light spray. The serious objection to the device is the amount of power required to throw even a moderate amount of fluid."

At this time (1895) manufacturers began to use a stream of water as the obstruction. This was done by making two openings at the outer extremity of the nozzle, these orifices being placed at such an angle that the discharge from the orifices met each other with such force that the solid streams were broken up into a coarse spray having a fan-shape. This group of nozzles has practically gone out of use and is represented by only the "Calla" and "Sprinkle" nozzles. In 1898 a patent was granted John Bean for a nozzle introducing new principles in nozzle construction, but intended to be an improvement on the Cyclone and Vermorel nozzles. The principles involved in its construction are well illustrated by the "Myers Power" nozzle with disgorger. It consisted of a hollow shaft through which the spray material passed, with a sliding cap covering the end of the hollow shaft. The spray was given a whirling motion by passing through a screw in the hollow shaft. On the shaft was a disgorging pin and to disgorge the nozzle it was only necessary to put the nozzle against a tree, limb, or some other object.

Very little or nothing was done to improve the spray thrown by the Vermorel nozzle or what attempts were made resulted in a much coarser spray. The nozzles were heavy and hard to handle when spraying among the tree branches because of their catching.

The Vermorel nozzles discharged a spray that would carry a distance of only 5 to 7 feet and as extension rods were not in use at that time this distance was not sufficient. Many inventors experimented with modifications of the Vermorel nozzle to increase the carrying power of spray. In most cases they sacrificed the fineness of the spray which was so desirable, for a coarse spray that would carry to a greater distance.

Extension rods then came into use, iron pipe perhaps being used first, later the much lighter and more easily handled bamboo rods. But even with this improvement there were many objections to the methods of applying the spray materials, chief of these were: (1) capacity of Vermorel nozzles was too small for orchard spraying (this was overcome by use of clusters of 2, 3 or 4 nozzles), (2) the clusters of nozzles were so heavy as to tire a man quickly, (3) the clusters were always catching on the branches, causing much trouble, (4) the nozzles dripped badly and were a source of much annoyance to the operator as well as a waste of materials, (5) in applying materials that contained compounds in suspension, as Bordeaux mixture, the nozzles frequently became clogged and gave more or less trouble in disgorging.

On April 25, 1900, George J. Winkle, of Seneca Falls, New York, secured a patent on a nozzle in which he used a spiral screw to cause the spray material to whirl instead of being admitted through an opening tangential to the eddy-chamber as in the Vermorel nozzles. Thus, he did away with the angle on the nozzle and made it much more compact and easier to operate.

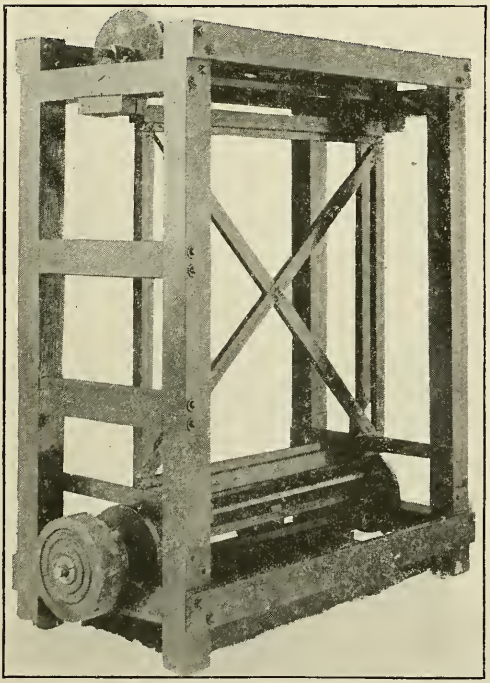

Fig 1.—Showing the Detailed Structure of the Machine Used in Recording the Distribution of the Spray.

The Vermorel nozzles, in spite of all their imperfections, remained in favor until about 1904. At this time there was a demand for a nozzle which would produce a finer spray at a wider angle and be of larger capacity than the Vermorel nozzle. In response to this demand, Gould Manufacturing Company conceived the idea that increasing the size of the eddy-chamber would produce the spray desired and began to experiment. They made six experimental nozzles varying the width of the eddy-chamber from one-half to one and one-half inches. They [20] write, "We carefully tested these nozzles and found the quality of the

[20] Extract from letter dated March 7, 1916, of Gould Manufacturing Company, Pittsburg Office.

spray increased with the size of the eddy-chamber, and that we were able to produce a very fine spray at a much lower pressure than with the old nozzles. We selected the one and the one-half inch diameter chambers as giving the best results and most practical to use, calling the one inch size our large Mistry and the one-half inch size our small Mistry. As we have already stated, the success of these nozzles depended on the large eddy-chamber and increasing the size of this chamber was our own idea." This nozzle met with success and was used and recommended by the experiment stations from 1904 until those of the disc type came into use.

Still the Mistry nozzles were not without fault because in applying such materials as Bordeaux mixture and lime-sulphur solution, there were some undissolved particles that even with the disgorgers gave a great deal of trouble by clogging. Power sprayers were just coming into general use and nozzles of larger capacity were demanded. Again the Gould Manufacturing Company took up this problem and in the early part of 1906 began to design and experiment on a new nozzle which would produce a very fine mist, have good carrying power, discharge the spray at a wide angle, and overcome the disadvantage of clogging.

After much experimenting they made the first Mistry Jr. nozzle on August 21, 1906. This nozzle embodied a new feature in nozzle construction, that of the directing disc or the basal plate containing the oblique holes which gives the spray material its whirling motion. The Mistry Jr. nozzles were a great improvement over the Mistry nozzles and the fruit growers took them up readily. In a short time numerous other manufacturers of spray nozzles adopted the principles contained in this nozzle and with minor changes manufactured nozzles of great similarity, until the grower became confused with the multiplicity of nozzles of this type.

Some of the changes made in the construction of the nozzles have been beneficial, while a number have been detrimental.

F. E. Myers & Brother put out a nozzle under a patent of September 28, 1909, known as the "Power with Disgorger." This nozzle contained a wide eddy-chamber and a spiral screw which imparted a whirling motion to the spray. It also contained a disgorging pin so constructed that the nozzle was disgorged by pushing against a limb.

Strainers have been placed in the base of the nozzles and the position, shape and arrangement of the supply holes in the directing disc have been changed from time to time, but the main principles employed in the construction of the eddy-chamber nozzles as we know them today have been but little changed since Gould Manufacturing Company made their Mistry Jr. nozzle.

REASONS FOR MAKING A STUDY OF SPRAY NOZZLES

As has already been pointed out, many of the spray nozzles used today by the fruit growers are not adapted to the purpose to which they are put, thus causing a great waste in time and materials. We frequently see spray injury both on the foliage and the fruit that is caused by improper methods of application and in many cases the fault lies directly with the nozzle and could be avoided if a nozzle having the proper distribution were used. Much can still be learned of spray nozzles and the principles underlying their construction, since the development has been so recent. The field is so bright for the inventor that the market has been flooded with a great number of nozzles of all descriptions, some good and some bad. The imperfections as well as the good points to be found in the various spray nozzles should be brought to light and this has been the object of the writer. It was considered worth while to make a test of the capacity of the nozzles used in the distribution study in order that recommendations as to the best nozzle to use for different spraying operations could be more accurately made; also, to determine if possible some of the principles of nozzle construction which exert more or less influence on their rate of discharge as well as on their distribution.

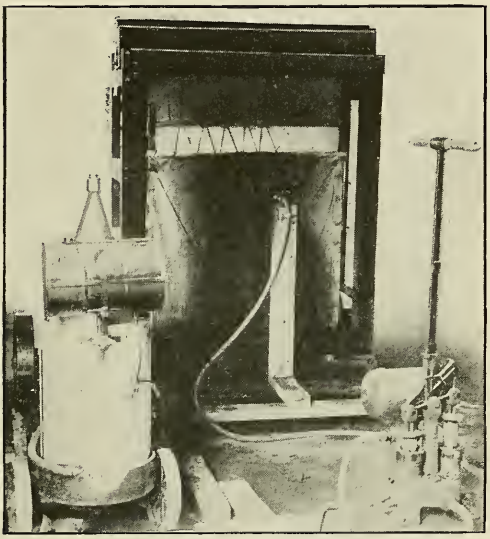

Fig. 2.—Apparatus Used in Studying the Distribution of the Spray Discharged.

DESCRIPTION OF APPARATUS USED IN STUDYING THE DISTRIBUTION OF SPRAY NOZZLES

In order to study the distribution of the spray discharged from the nozzles, some method of recording all the drops with their location and relative size had to be devised. Some time before this work was begun, Riley of Cornell University designed and built a machine he called a "sprayograph." The machine used in this work is a modification of the one used by Riley. This machine works on the same principle as the focal plane shutter, and consists of a curtain of water-

proofed canvas carried by two endless belts, one at each side. The belts revolve over two wooden rollers nine inches in diameter. The ends of the curtain do not meet by a distance which determines the width of the slot across the face of the focal plane shutter. Strong wooden strips were tacked to the ends of the curtain in order to hold them true, but this was unsatisfactory as the strips soon became loose. The ends of the curtain were then held by diagonal lacing. Above the upper roller was placed a hood to protect the operator from flying drops of spray.

Paper carried by a sliding frame or plate was introduced between the sides of the curtain as it hung between the two rollers. The paper used in recording the results was "white news" size thirty-eight by fifty inches.

The curtain was driven by power applied to the lower roller from a small gasoline engine having a friction clutch on the drive wheel so that the curtain could be stopped while the record sheets were being changed. For holding the nozzles firmly in position, a stand was made in such a way that it could be moved to any distance from the machine but still holding the nozzle in position.

The spray was kept at a uniform pressure by a double action hand pump having a pressure gauge attached which had been calibrated and all readings corrected.

TIME OF EXPOSURE

The speed of the curtain and the size of the opening in the curtain determined the length of time the paper was exposed to the spray. By increasing the speed of the curtain or by decreasing the size of the opening, the time of exposure would be decreased. The time of exposure determined the amount of spray that struck the paper. If the time of exposure was too long the drops of spray merged and gave a blurred record but if the exposure was just right, each drop could be distinctly seen. After making many tests it was found that the best results were obtained when the curtain made sixty revolutions with an opening of three and one-half inches or an exposure of .02365 second.

MATERIAL USED FOR SPRAY

Difficulties were encountered in securing some material or coloring matter that would color water dark enough to be seen and photographed. A number of materials were tested. Diamond dyes in three colors: vermilion, dark blue, and black gave good results but they had to be used so concentrated that the cost prohibited their use. An ink made of tannic acid and ferric chloride was used but proved to be worthless as the color was not dark enough. A solution of ferric chloride and gallic acid was tried, but was of no value for this purpose

as the color was too indistinct when broken into fine mist. The same was true of solutions of potassium permanganate and calcimine.

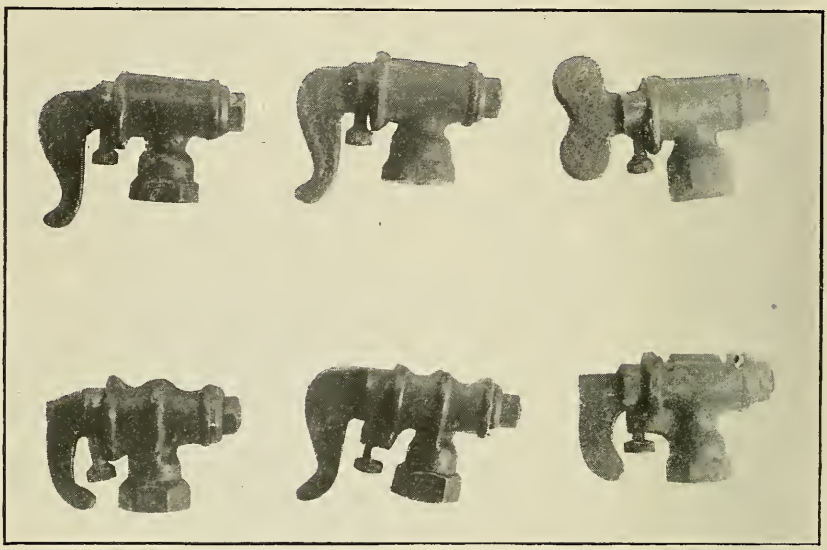

Fig. 3.—A Group of Bordeaux Nozzles.

Venetian red mixed in water at the rate of one pound to one gallon gave very good results with nozzles of large capacity, but the smaller capacity nozzles seemed to strain out some of the material and too light a color was produced. Trouble was also experienced in keeping the coloring matter in suspension.

A method of using black paper and whitewash was tried but it was found that the whitewash could not be made white enough to pass through the smallest openings of the nozzles without clogging them. When a thinner wash was used the nozzles broke it up into such fine mist that it could not be easily seen on the black paper.

Various analine dyes such as "Scarlet 2 R. L.," "Nap Yellow," "Yellow M. X. X. Concentrated," and "Orange Y" were used. The "Orange Y" gave the best results as it was free from admixture of blue. This dye dissolved in water making a bright red solution and on the white paper after drying was a reddish-orange color. The dye was procured of Heller & Merz of Newark, N. J. This dye was used in making all of the distribution tests.

NOZZLES

A collection was made of all of the important spray nozzles offered for sale in the United States at the time this work was begun. Particular effort was made to secure all nozzles of the disc or eddy-chamber

type. As the nozzles were secured from the manufacturer they were given a number and were tested under this number throughout. Before the nozzles were tested in any way they were measured with micrometer calipers.

METHOD OF MAKING TESTS

After the nozzle and the paper used to record the results were in place, the machine was started and allowed to make a few revolutions so as to reach its maximum speed. When the opening in the curtain was at the bottom of the machine the nozzle was turned on and was allowed to play on the curtain until it had made one revolution, and was then turned off. The recording paper was then removed and allowed to dry. The nozzle was then moved back a certain distance from the curtain and the test made over again. The tests were made from one to four feet from the curtain, thus giving an opportunity to study the distribution at different distances from the object sprayed.

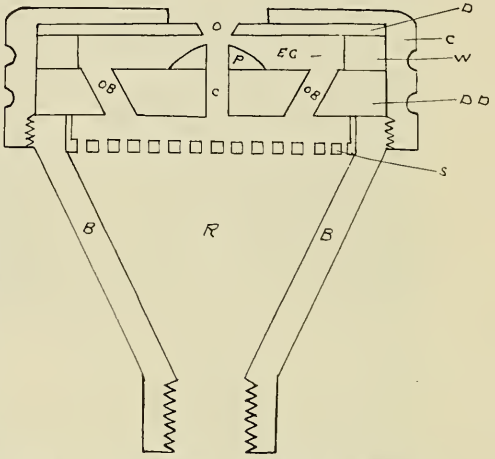

Fig. 4.—Diagram of longitudinal section of a spray nozzle showing all of the parts that may be found in the eddy-chamber nozzles. O, orifice; EC, eddy-chamber; P, post on the directing disc, DD; C, Cap; W, washer; OB, oblique supply holes; S, strainer; R, reservoir; B, base of nozzle; D, disc, C, central supply hole.

Pressures of seventy-five and two hundred pounds were used. At these pressures an opportunity was given for studying the distribution due to increased pressure. In the following tables, unless otherwise noted, the pressure used was seventy-five pounds.

RESULTS OF THE DISTRIBUTION TEST

The discharge of the nozzles varied so much and, since there were no clear-cut lines to direct the measurements, much had to be left to the discretion of the writer in making them. The diameter of the cone was taken to the outside of the heavy portion of the ring. The scattered drops outside of the ring were not taken into account in this measurement. In securing the width of the ring the width of the heaviest portion of the spray was used. In the tables that follow, the records were taken at a distance of two feet from the nozzle at seventy-five pounds pressure.

INFLUENCE OF OUTLET ORIFICE ON DISTRIBUTION

The size of the outlet orifice has much to do with the angle (diameter of the cone) at which the spray is discharged. When the diameter of the outlet orifice is increased the angle of discharge becomes greater, this is shown by a comparison of columns 2 and 7 of

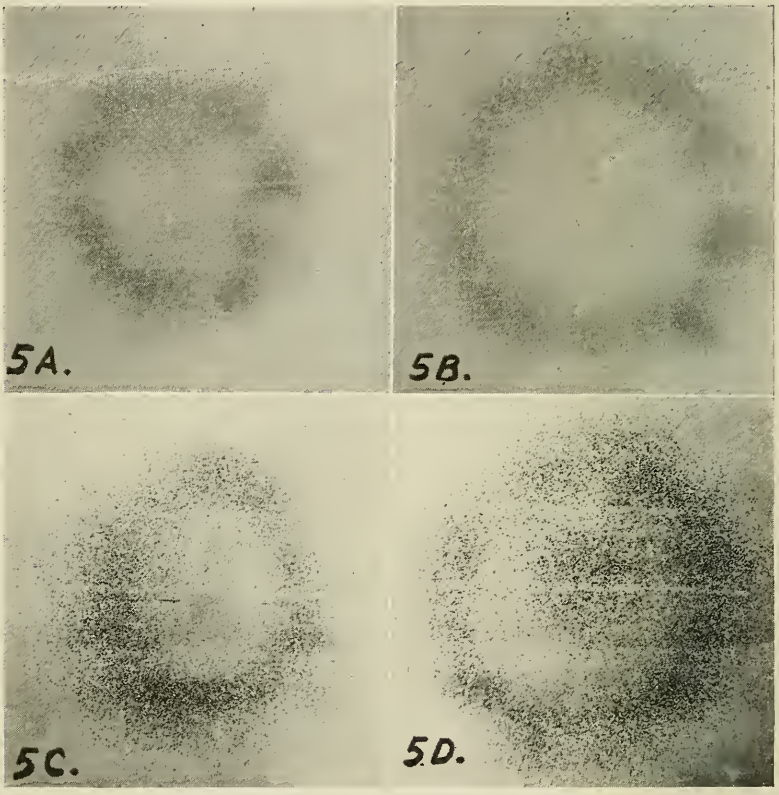

Fig. 5.—Influence of the size of outlet orifice on the distribution of the spray:
A, Distribution of the Friend Regular nozzle, diameter of orifice 2.00 mm.
B, Distribution of the same nozzle, size of orifice increased to 3.2 mm.
C, Distribution of the New Eclipse nozzle, diameter of orifice 2.0 mm.
D, Distribution of the same nozzle, size of orifice increased to 2.8 mm.

Table 1. An increase in the diameter of the outlet orifice of .4 mm. may, however, in the case of one nozzle (Friend Regular) widen the angle of discharge four degrees, while with another nozzle (Tiger Strainer) an increase of eighteen degrees was secured. There are so many factors other than the area or diameter of the outlet orifice which have more or less influence on the angle of discharge, and which

modify or exaggerate the effect of the orifice that a general statement regarding the results that might be expected from a definite increase in the area of the orifice cannot be made.

TABLE I.—Influence of Outlet Orifice on Distribution

NOZZLE	Diameter of Orifice in mm.	Area of Orifice in sq. mm.	Sq. mm. Increase in Area Over Smallest Orifice	Diameter of Cone in Inches	Width of Ring in Inches	Angle of Discharge	Increase in Angle of Discharge	Increase per sq. mm. Increase in Area of Orifice
Friend Regular	2.0	3.1416	0000	22	8	67	0	000
Friend Regular.	2.8	6.1576	3.016	38	9	76	9	2.98
Friend Regular.	3.2	8.042	4.900	40	10	80	13	2.65
Tiger Strainer	1.2	1.131	0000	24	7	52	0	000
Tiger Strainer	1.6	2.0106	0.8796	34	8	70	18	20.46
Tiger Strainer	2.0	3.1416	2.0106	44	8	84	32	15.91

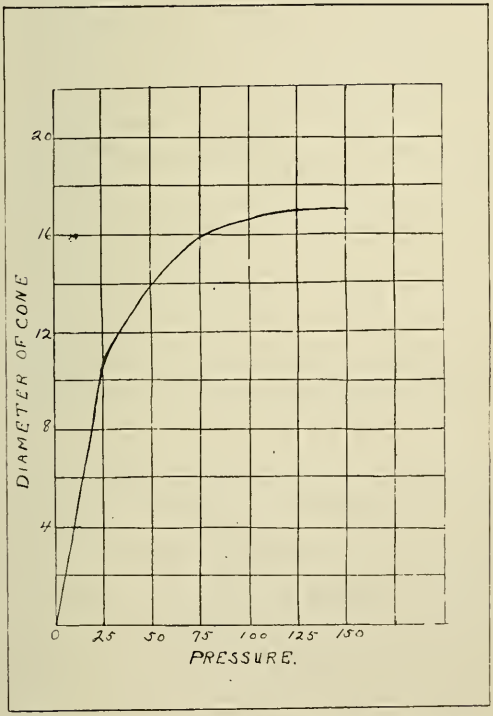

Fig. 6.—Influence of Pressure on the Diameter of the Cone of Spray Discharged (Mistry Jr. Nozzle, Diameter of Orifice 1.2 mm.).

As the area of the outlet orifice was enlarged, all other factors remaining constant, an increase in the angle of discharge was secured, but the rate of increase became less as the area of the orifice was made greater. When the area of the orifice of the Tiger Strainer nozzle was increased from 1.2 mm. to 1.6 mm. or an increase of .8796 sq. mm. the angle of discharge was widened 18° (Table 1, column 8) or 20.46° for each added sq. mm. of orifice. When the orifice diameter was increased to 2.0 mm. or 2.0106 sq. mm. greater than the smallest orifice, however, the angle of discharge was widened 32° or only 15.91° for each sq. mm. added. Thus, the rate of increase in the an-

gle of discharge diminished as the size of the orifice was increased.

This diminishing rate of increase may be explained by a supposed decrease in the centrifugal force with which the material whirls in the eddy-chamber. Thus, a spray is discharged at an angle which is due to the effect of the larger orifice minus the decrease due to the loss of centrifugal force.

It is generally believed that an increase in the size of the orifice increases the coarseness of the spray. This is not the case, for in all of the nozzles studied no appreciable difference could be noticed in the size of the spray particles as the diameter of the orifice was varied. With an abnormally large orifice or a very low pressure, the whirling motion in the eddy-chamber would diminish or be overcome and coarser discharge drops would result. An attempt was made to count the number of drops per square inch for the different sized orifices but the results were of little value because of uneven distribution in the different sectors of the cone.

INFLUENCE OF PRESSURE ON DISTRIBUTION OF SPRAY

Pressure was found to have considerable effect on the distribution of the spray. It exerted an influence on the angle of discharge, width of the ring of spray, and on the size of the spray particles.

The diameter of the cone or angle at which the spray was discharged was found to be increased up to a certain point, as the pressure was increased, at which the diameter of the cone reached its maximum and additional pressure had no effect. This is shown by Fig. 6. It will be noticed that the diameter of the cone increased rapidly at first and then less rapidly as additional pressure was applied. In the case of the Mistry Jr. nozzle having an outlet orifice of 1.2 mm. it was found that the maximum diameter of the cone was secured at 125 pounds pressure. It is to be expected that every nozzle must have some point at which all factors will work at their maximum and produce the best spray possible for the nozzle and where additional energy would be in a measure wasted.

As the pressure was increased and the angle of discharge became wider, the width of the heavy or main ring of spray decreased, as is shown by Fig. 7. At the low pressure of twenty-five pounds the spray discharge was a solid cone and no ring could be made out (Fig. 8) but at fifty pounds pressure a definite ring four and one-half inches wide was formed (Fig. 8). As the pressure became greater this ring became narrower (Fig. 8) until at one hundred and twenty-five pounds pressure the minimum width of three inches was secured. It is also well to note that it was at one hundred and twenty-five

pounds pressure that the maximum diameter of the cone of spray was secured.

The fact that the width of the ring of spray becomes narrower as the pressure is increased may possibly be explained in the following manner. As the pressure is increased so is the rapidity at which the material whirls in the eddy chamber and the force with which the spray material leaves the orifice makes the particles travel more compactly with less spreading in the rings.

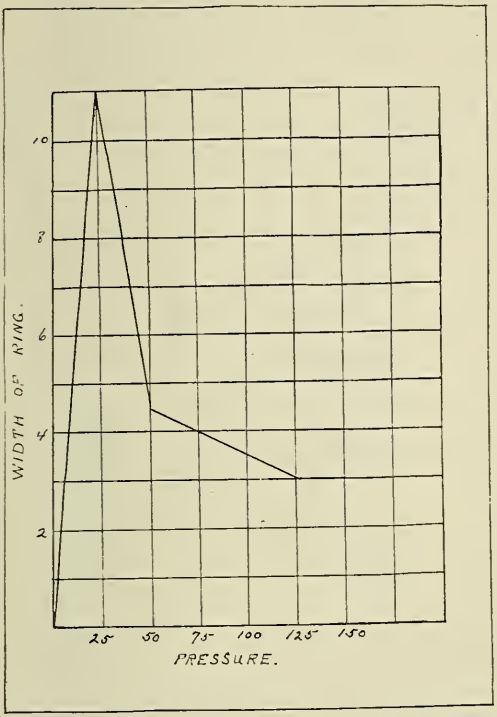

Fig. 7.—Influence of Pressure on the Width of the Ring of Spray Discharged (Mistry Jr. Nozzle, Diameter of Orifice 1.2 mm.).

The fineness of the spray was found to vary directly with the pressure. At twenty-five pounds pressure the drops were large and poorly distributed. As the pressure increased the drops became smaller and smaller until all the particles were almost entirely mist-like. The Mistry Jr. nozzle gave the best distribution at 125 pounds pressure. Up to this point there were imperfections showing in the cone of spray and at 125 pounds pressure they disappeared until very little was to be gained by higher pressure (Fig. 8).

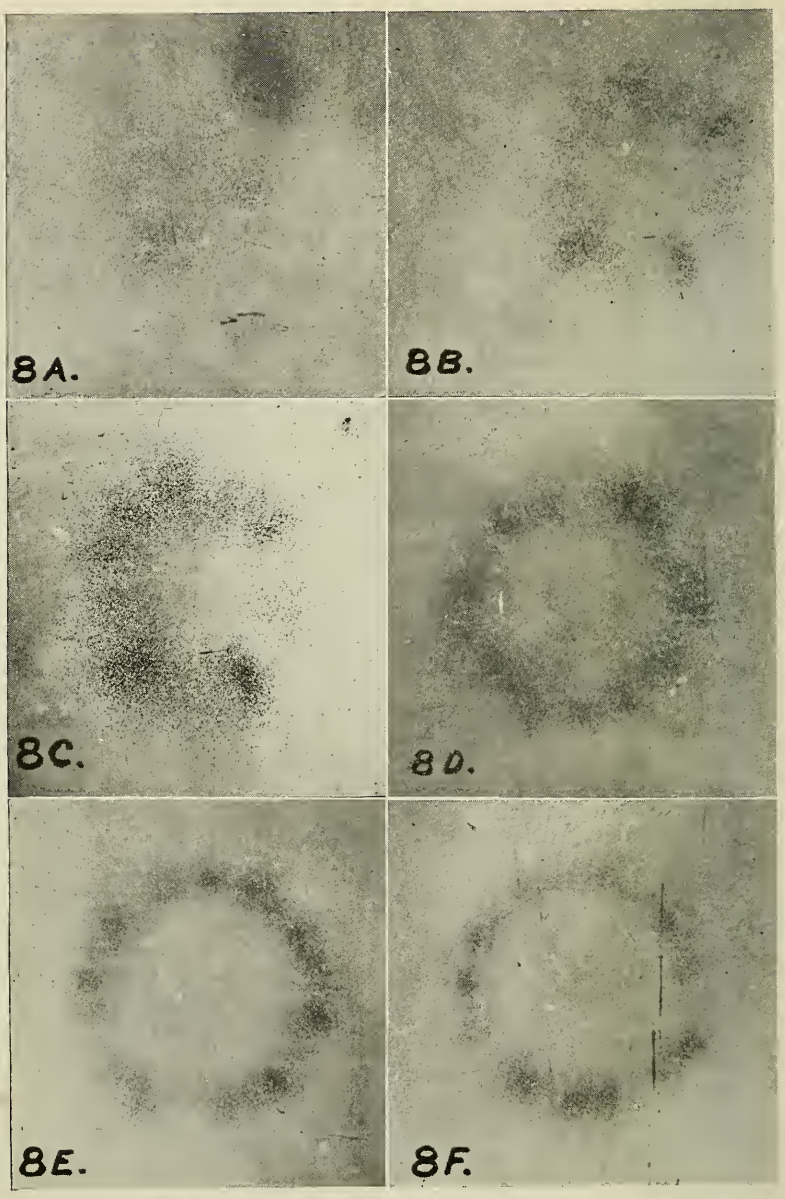

Fig. 8.—Influence of Pressure on the Distribution of Spray. Nozzle Used, Mistry Jr., Diameter of Orifice, 1.2 mm.

A, Distribution at 25 Pounds Pressure.
B, Distribution at 50 Pounds Pressure.
C, Distribution at 75 Pounds Pressure.
D, Distribution at 100 Pounds Pressure.
E, Distribution at 125 Pounds Pressure.
F, Distribution at 150 Pounds Pressure.

INFLUENCE OF DEPTH OF EDDY-CHAMBER ON DISTRIBUTION

TABLE 2.—Influence of Depth of Eddy-Chamber on Distribution.

NOZZLE	Diameter of Orifice in mm.	Depth of Eddy-chamber in mm.	Increase in Depth of Eddy-chamber in mm.	Diameter of Cone in Inches	Width of Ring in Inches	Angle of Discharge in Degrees	Degrees Difference in Angle of Discharge
Tiger Strainer	1.2	3.0	0.0	24	7	52	
Tiger Strainer	1.2	6.0	3.0	22	7	48	4
Tiger Strainer	1.6	3.0	0.0	34	8	70	
Tiger Strainer	1.6	6.0	3.0	32	7	68	2
Tiger Strainer	2.0	3.0	0.0	44	8	86	
Tiger Strainer	2.0	6.0	3.0	42	7	84	2
Scientific----	1.6	2.5	0.0	22	7	48	
Scientific----	1.6	5.0	2.5	20	7	45	3
Scientific----	1.6	7.5	5.0	18	6	42	6
Scientific----	2.3	2.5	0.0	32	9	68	
Scientific----	2.3	5.0	2.5	30	8	64	4
Scientific----	2.3	7.5	5.0	28	8	60	8

The depth of the eddy-chamber determines in a measure the angle at which the spray is discharged as well as the thickness of the ring (Fig. 9). In the case of the Scientific nozzle an increase of 5 mm. in the depth of the eddy-chamber narrowed the angle of discharge as much as eight degrees. (Table 2, columns 4 and 8.) It is also worth while to point out that as the eddy-chamber is made deeper, all other

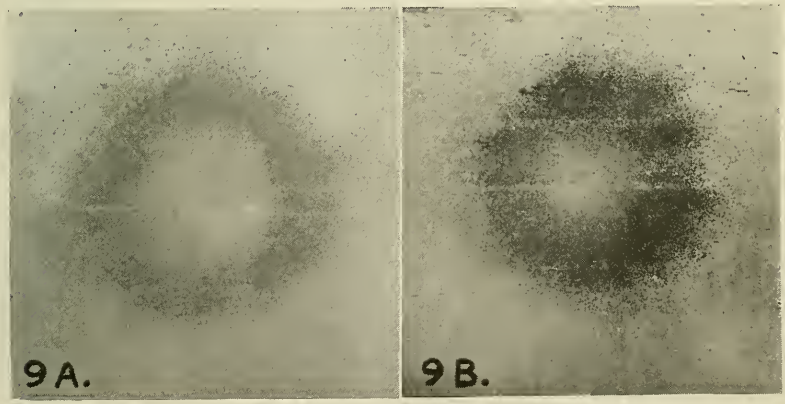

Fig. 9.—Influence of the Depth of the Eddy-chamber on the Distrbution of the Spray. Nozzle Used, Scientific; Diameter of Orifice 2.3 mm. A, Distribution of the Spray When the Eddy-chamber was 2.5 mm. Deep. B, Distribution When the Depth of the Eddy-chamber had Been Increased to 7.5 mm.

factors remaining constant, the angle of discharge is decreased at a constant rate. This is illustrated by the Scientific nozzle (Table 2, columns 4 and 8); in this case no other factors enter in to modify the results. Using an orifice of 2.3 mm. in diameter and increasing the

depth of the eddy-chamber from 2.5 mm. to 5.0 mm., the angle of discharge was narrowed 4 degrees. When the eddy-chamber was again made 2.5 mm. deeper, the angle of discharge was narrowed 4 degrees more or a total of 8 degrees decrease.

As the depth of the eddy-chamber was increased, the walls of the cone or ring of spray became narrower (Table 2, columns 3 and 6). The center of the cone contained many more mist-like particles but in every other respect the distribution of the spray remained the same.

Very little difference could be noticed in the size of the drops or spray particles discharged, but it appeared as though they were larger as the depth of the eddy-chamber was increased. This is what would naturally be expected, as any factor which would tend to cause the spray discharged to become a solid stream would tend also to increase the size of the particles.

INFLUENCE OF WIDTH OF EDDY-CHAMBER ON DISTRIBUTION

Only a small amount of work was done on the influence of the width of the eddy-chamber on distribution. This factor was found the most difficult to study because of the changes that would have to be made in the construction of the nozzle. The results secured, however, indicate that all other conditions remaining the same, an increase in the width of the eddy-chamber increases the angle of discharge and causes the ring of spray to become wider. A narrow eddy-chamber discharges a narrow-angled spray and the walls of the cone are more concentrated or are closer together, making a narrower ring of spray.

INFLUENCE OF ANGLE OF SUPPLY HOLES IN DIRECTING DISC ON DISTRIBUTION

The angle at which the supply holes are drilled in the directing disc or basal plate was found to influence greatly the angle at which the spray was discharged. In the case of the Mistry Jr. nozzle, having an outlet orifice of 2.5 mm. in diameter, a difference of fifteen degrees in the angle of the supply holes in the directing disc changed the angle of discharge as much as twelve degrees (Table 3). When the outlet orifice was 1.2 mm. in diameter a difference of only eight degrees was obtained under the same conditions. It will also be noticed that when the size of the outlet orifice was made greater, a larger decrease in the angle of discharge resulted (Table 3, columns 2 and 7). In a general way similar results were obtained with other nozzles tested.

The decrease in the angle of discharge due to the greater angle of the supply holes in the directing disc is what naturally would be expected. The smaller the angle of the supply holes, the greater would be the velocity at which the spray material would whirl in the eddy-chamber. The centrifugal force produced would tend to overcome the tendency of the material to travel in a straight line, and thus a wide angle of discharge would result.

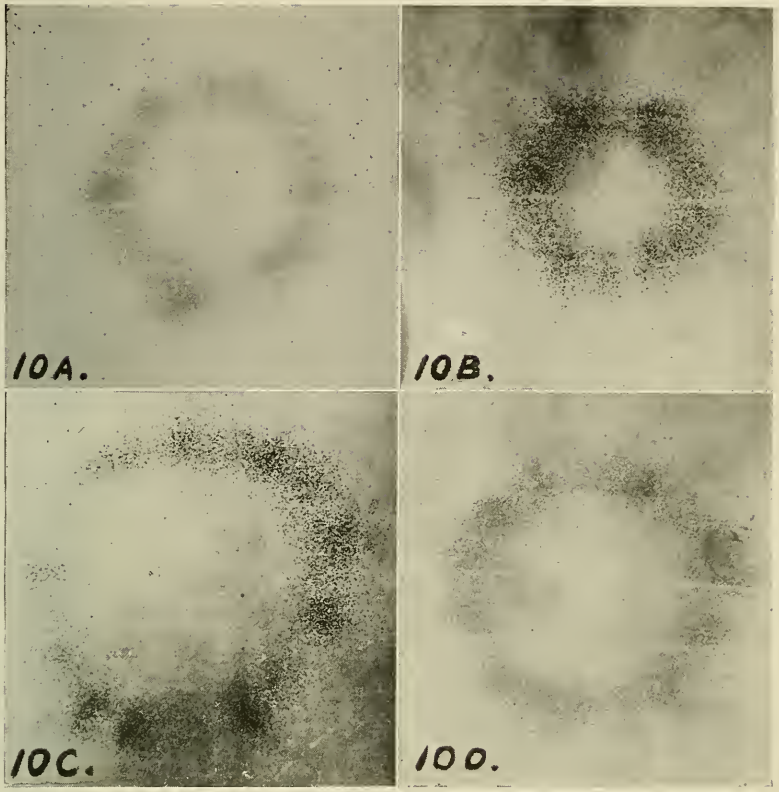

Fig. 10.—Influence of the Angle of Supply Holes on the Distribution of the Spray. Nozzle Used, Mistry Jr. A, Diameter of Orifice 1.2 mm., Supply Holes at 45 Degrees. B, Same Orifice, Supply Holes at 60 Degrees. C, Diameter of Orifice 2.5 mm., Supply Holes at 45 Degrees. D, Same Orifice as C., Supply Holes at 60 Degrees.

TABLE 3.—Influence of Angle of Supply Holes in Directing Disc on Distribution.

NOZZLE	Diameter of Orifice in mm.	Angle of Supply Holes in Degrees	Diameter of Cone in Inches	Width of Ring in Inches	Angle of Discharge in Degrees	Decrease Due to Greater Angle
Mistry, Jr.	1.2	45	32	8	68	
Mistry, Jr.	1.2	60	28	7	60	8
Mistry, Jr.	2.5	45	44	9	86	
Mistry, Jr.	2.5	60	36	8	74	12

The angle of discharge was decreased due to the greater angle of the supply holes, as well as the width of the ring. (Columns 5 and 7 of Table 3.) The investigations made by the writer and similar investigations by other experiment station workers, show that any factor, excepting pressure, that increases the angle of discharge also widens the ring of spray. The explanation has been given under the heading, Influence of Pressure on Distribution. The supply holes drilled at an angle of forty-five degrees also produced a spray which was made up of smaller drops than was secured when the holes were drilled at an angle of sixty degrees (Fig. 10).

INFLUENCE OF CENTRAL SUPPLY HOLE IN THE DIRECTING DISC ON DISTRIBUTION

Several nozzles now on the market have a basal plate or directing disc which contains a hole drilled vertically through the disc and is placed so that it comes directly under the outlet orifice. This hole is in addition to the oblique holes drilled at the edge of the directing disc. It was noticed when studying the factors governing the rate of discharge that the presence of the central supply hole increased the rate of discharge. In a study of the distribution of the spray it was found that the central supply hole filled up the center of the cone, thus making a solid cone. It also decreases the angle of discharge and increases the size of the drops or spray particles.

TABLE 4.—Influence of Central Supply Hole in Directing Disc on Distribution.

NOZZLE	Diameter of Orifice in mm.	Central Supply Hole 1.2 mm. in Diameter	Diameter of Cone in Inches	Width of Ring in Inches	Angle of Dicharge in Degrees	Dif. in Angle of Discharge Due to Central Hole
New Eclipse	2.0	Open	34	34	70	
New Eclipse	2.0	Closed	36	7	74	4
New Eclipse	2.8	Open	40	40	80	
New Eclipse	2.8	Closed	44	8	86	6

In the case of the New Eclipse nozzle having an outlet orifice 2.0 mm. in diameter, the character of the spray discharged was changed from a solid cone to a hollow cone by closing the central supply hole which was 1.2 mm. in diameter (Table 4, columns 2 and 5). The diameter of the spray was increased and the angle of the discharge was changed from 70 to 74 degrees, or the angle of the spray was widened 4 degrees (Fig. 11). When a larger outlet orifice was used, the increase in the angle of discharge was greater, as will be noticed

in column 6 of Table 4. The results are characteristic of all the nozzles tested that have the central hole in the directing disc.

The spray particles were somewhat larger when the center hole in the directing disc was used, and with the larger sized outlet orifices this was much more pronounced. The size of the central supply hole has much to do with the character of the spray discharged, as this hole

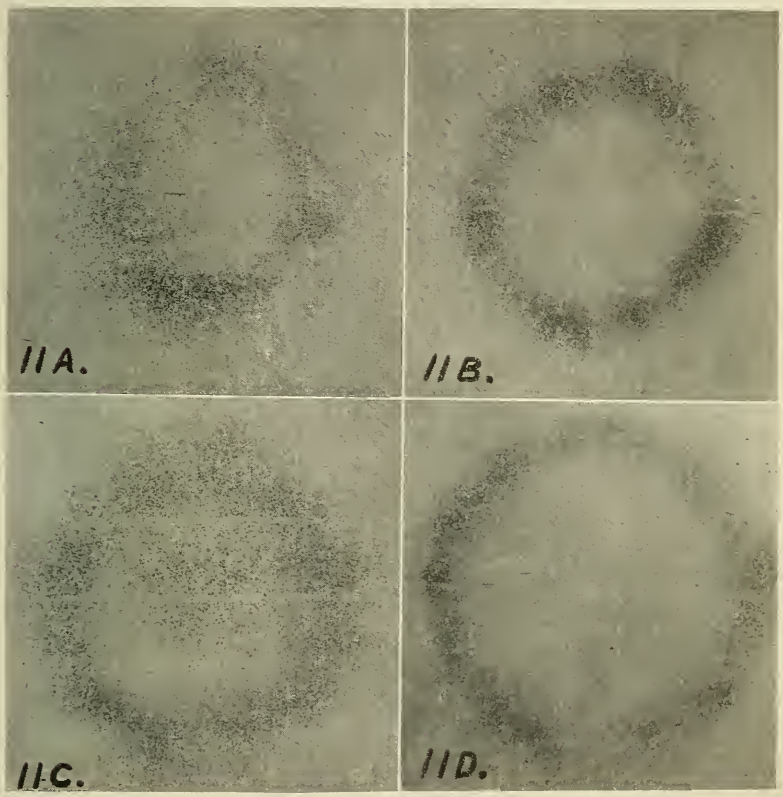

Fig. 11.—Influence of the Central Supply Hole on the Distribution of the Spray Discharged by the New Eclipse Nozzle. A, Diameter of Orifice 2.0 mm., Central Supply Hole Open. B, Orifice Diameter the Same as in A, Central Supply Hole Closed. C, Diameter of Orifice 2.8 mm., Central Supply Hole Open. D, Diameter of Orifice the same as in C, Central Supply Hole Closed.

seems to exert a greater influence on the distribution than the holes in the outer edge of the disc. Some nozzles have a central supply hole that is as large as 2.5 mm. in diameter, which in proportion to the other dimensions of the nozzle is too great and a solid cone of spray is discharged which has numerous large drops in the center. If a center

hole is to be used it should be small as there is danger of its overcoming the tendency of the holes in the outer edge of the directing disc to make a wide, finely broken up spray.

In the formation of a hollow cone spray, the whirling of the material in the eddy-chamber causes it to pass out over the edges of the outlet orifice, thus producing a hollow cone. Only a very small part, if any, of the material passes out through the center of the orifice so when the central hole is placed in the directing disc there is produced two different kinds of currents in the eddy-chamber: one which revolves and the other which flows in a straight line. In this way the center of the hollow cone is filled and a solid cone is produced. The two currents tend to counteract each other, with the result that a narrower angled spray is produced. The central current is broken up and fills the center of the cone with small particles, provided the hole is in the right proportion to the rest of the nozzle.

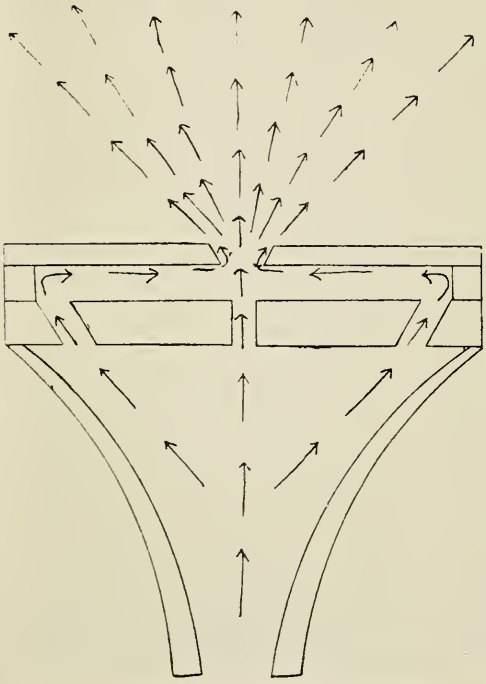

Fig. 12.—Diagram Showing How the Addition of a Central Supply Hole Changes the Character of the Spray From a Hollow Cone to a Solid Cone.

INFLUENCE OF NUMBER OF SUPPLY HOLES IN THE DIRECTING DISC ON DISTRIBUTION.

Goodwin[21] of the Ohio Agricultural Experiment Station was perhaps the first to notice that the number of supply holes in the directing disc determined in a large measure the distribution of the spray discharged. He recommended that four holes be used in the directing disc as these made the supply of material come from four quadrants instead of from one or two and thus evened up the spray as it passed through the outlet orifice.

For the purpose of studying the effect of one and two holes in the directing disc on distribution, the Simplex nozzle was used. This

[21] Goodwin, W. H., Spraying Machinery—Ohio Agr. Exp. Sta. Bul. 216 (1910) p. 500.

nozzle as put on the market has two holes in the basal plate. To study the effect of having only one present, but in every other respect exactly the same, one of the holes was plugged up with soft wood.

One hole in the edge of the directing disc was found to increase the angle of discharge six degrees, and to widen the ring of spray one

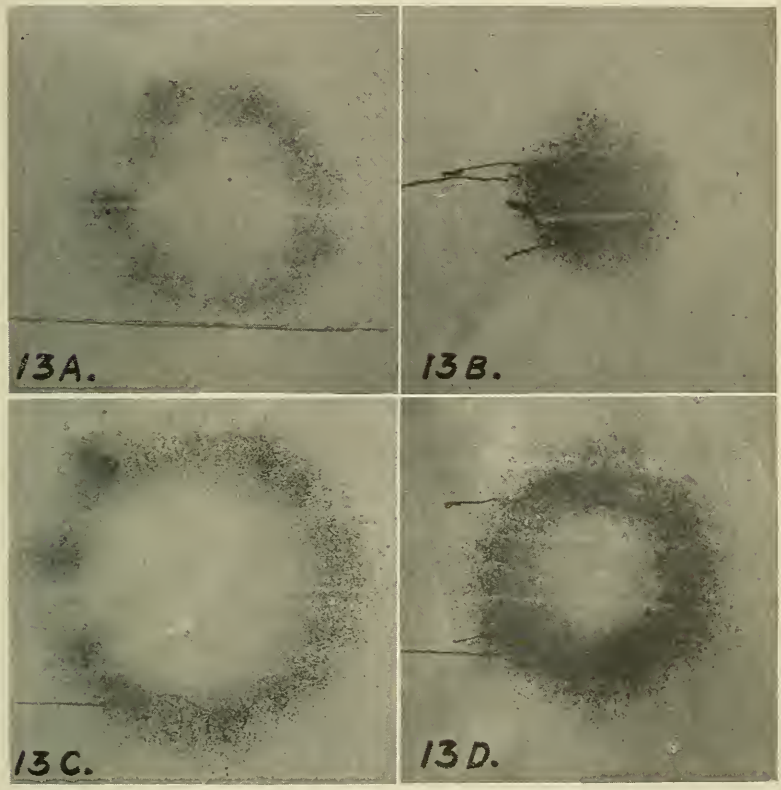

Fig. 13.—Influence of the Area of the Supply Holes on the Distribution of the Spray. A, Distribution of the Friend Regular Nozzle; Diameter of Orifice, 2.0 mm.; Area of Supply Holes 25.1328 sq. mm. B, Distribution of the Friend Calyx Nozzle (Which is Similar to the Friend Regular Nozzle Except that the Area of the Supply Holes is 75.3984 sq. mm. or Three Times That of the Friend Regular Nozzle). C, Distribution of the Friend Regular Nozzle; Diameter of Orifice, 3.2 mm.; Area of Supply Holes 25.1328 sq. mm. D, Distribution of the Friend Calyx Nozzle; Diameter of Orifice, 3.2 mm.; Area of Supply Holes, 75.3984 sq. mm.

inch at a distance of two feet (Table 5). The spray discharged, using one hole, was one-sided and one-half of the ring was almost entirely gone, while with two holes the discharge was an almost perfect cone. The size of the spray particles remained the same as well as could be told by observation. The spray produced by the Simplex

nozzle, having the two supply holes, has many very tiny mist-like particles distributed in the center of the cone; but when only the one supply hole was used there was practically none.

TABLE 5.—Showing Influence of Supply Holes in Directing Disc on Distribution.

NOZZLE	Diameter of Orifice in mm.	No. of Supply Holes	2 FEET			
			Diameter of Cone in mm.	Width of Ring in Inches	Angle of Discharge in Degrees	Degrees Difference Due to Smaller No. of Holes
Simplex	1.6	2	30	7	64	
Simplex	1.6	1	34	8	70	6
Simplex	2.0	2	34	8	70	
Simplex	2.0	1	38	9	76	6
Friend Calyx	2.0	6	18	18	44	
Friend Regular	2.0	2	32	8	68	24
Friend Calyx	2.8	6	28	8	60	
Friend Regular	2.8	2	38	9	76	16
Friend Calyx	3.2	6	32	9	68	
Friend Regular	3.2	2	42	10	84	16

To study the influence of using more than two supply holes on distribution, the Friend Regular and Friend Calyx nozzles were used. These nozzles are alike in every respect other than that the Regular nozzle has two supply holes and the Calyx nozzle has six. The same outlet orifices were used in both nozzles to avoid any differences.

Here the same results were secured as with the Simplex nozzle. The six supply holes reduced the angle of discharge as much as twenty-four degrees and increased the width of the ring of spray about one inch, two feet from the nozzle, except in the case of the Friend Calyx nozzle, when an outlet orifice 2.0 mm. in diameter was used a solid cone was obtained (Fig. 13).

The six holes in the directing disc increases the number of spray particles distributed in the center of the cone, also slightly increases the size of the particles discharged in the main ring. By increasing the number of supply holes, all other factors remaining the same, the effective spraying distance of the nozzle is increased, or in other words, the spray produced has more driving power. Many manufacturers have overcome this when using as many as four supply holes by reducing the angle of the holes, which overcomes the narrowing of the angle of discharge, and destroys the driving power of the spray.

The results secured indicate that in a properly proportioned nozzle, two supply holes give as good results as more. One is not sufficient as in every case a one-sided spray is produced. When two supply holes are used and no flaws in manufacturing exists, the spray

discharged is as perfect as the most critical could desire. When the nozzle is not correctly made, four holes or more will help to cover up the imperfections.

INFLUENCE OF POST ON THE DIRECTING DISC ON DISTRIBUTION

A few nozzles now on the market have a raised place on the directing disc that is located just under the outlet orifice. This has been called by the writer a "post" as this is a word that seems to describe it best. In studying the influence due to the post on the directing disc the Whirlpool nozzle was used because the directing disc could be taken out and turned over, thus removing the post from within the eddy-chamber.

TABLE 6.—Influence of Post on the Directing Disc on Distribution.

NOZZLE	Diameter of Orifice in mm.	Post Present	Central Supply Hole	Diameter of Cone in Inches	Width of Ring in Inches	Angle of Discharge in Degrees	Decrease in Angle Due to Post
Whirlpool-	1.6	Yes	Open	22	22	48	4
Whirlpool	1.6	No	Open	24	24	52	
Whirlpool-	1.6	Yes	Closed	24	7	52	4
Whirlpool-	1.6	No	Closed	26	8	52	

The post was found to narrow the angle of the spray discharged about four degrees (Table 6, column 8) in both cases when the central supply hole was open and when it was closed (Fig. 14). It will also

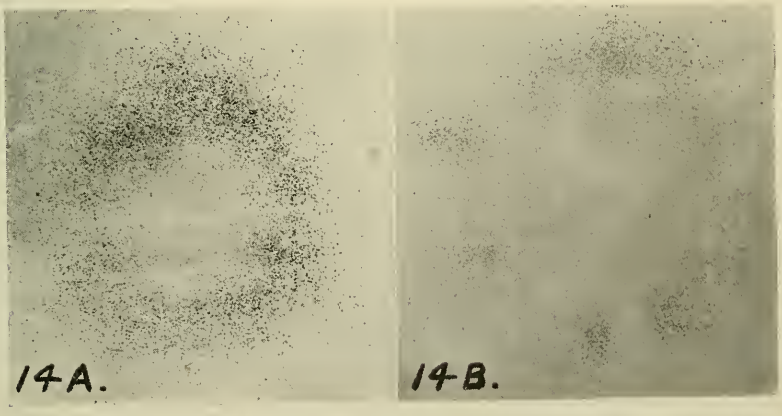

Fig. 14.—Influence of a Post on the Directing Disc With Reference to the Distribution of Spray. A, Distribution of the Spray Discharged From the Whirlpool Nozzle With a Post on the Directing Disc. B, Distribution of the Spray Discharged From the Same Nozzle Without the Post.

be noticed (Table 6, column 6) that when the central supply hole was closed the character of the spray was changed from a solid cone to a hollow cone in both cases when the post was present and when it was absent. In the case of this nozzle, the central supply hole narrowed the angle of discharge four degrees.

The post on the directing disc makes the spray discharged much more even. A more nearly perfect solid or hollow cone is produced which has the spray particles more perfectly distributed. In this way many of the slight imperfections in the nozzle are overcome. When the post was up or facing the outlet orifice and the central supply hole was closed, very little difference could be noticed in the size of the spray particles, from the discharge produced when the post was down or facing the supply hole. But when the central supply hole was open, the presence of the post increased the size of the spray particles slightly, making the spray somewhat coarser.

The reasons why a post on the directing disc should narrow the angle of discharge, cause the discharge to be more evenly distributed, and in some cases increase the size of the spray particles is hard to explain. A possible explanation follows: Any mechanical means that tends to cause the spray material to whirl in an even narrow stream without any conflicting currents in the eddy-chamber will certainly produce a spray that will have a narrower angle, a thinner ring of spray, and a better or more evenly distributed discharge.

It is also reasonable to believe that anything that could produce the results mentioned previously, would also tend to cause the spray particles to be larger in size as the material is more compact and is discharged in a smaller area.

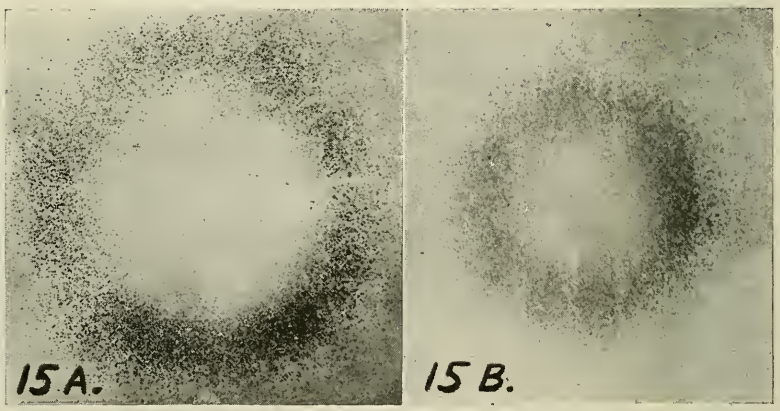

Fig. 15.—Influence of Thickness of Disc on Distribution. A, Distribution of the Painting Nozzle With a Disc 0.5 mm. Thick. B, Distribution of the Same Nozzle With a Disc 1.0 mm. Thick.

INFLUENCE OF THICKNESS OF DISC ON DISTRIBUTION

The thickness of the metal surrounding the outlet orifice was found to exert a great influence on the distribution of the spray discharged. A difference of .5 mm. in the thickness of the disc narrowed the angle of discharge eighteen degrees in the case of the Painting nozzle (Table 7, columns 3 and 7). In the case of other nozzles tested, a thicker disc was found to narrow the angle of discharge, the amount varying with different nozzles.

TABLE 7.—Influence of Thickness of Disc on Distribution.

NOZZLE	Diameter of Orifice in mm.	Thickness of Disc in mm.	Diameter of Cone in Inches	Width of Ring in Inches	Angle of Discharge in Degrees	Degrees Difference Due to Thicker Disc
Painting	1.8	.5	36	9	74	
Painting	1.8	1.0	26	7	56	18

It will also be noticed (Table 7, column 5) that a thicker disc decreased the width of the ring of spray. Considerable difference could be noticed in the size of the spray particles between a disc .5 mm. thick and a disc that was 1.0 mm. in thickness. The thicker disc caused the spray particles to be larger and resulted in a coarser spray (Fig. 15).

The results obtained in this study are in a measure contradictory to those secured by Hewitt,[22] as he found that a thicker disc did not alter the angle of the spray discharged, but made the walls of the cone or ring of spray narrower, and at the same time the size of the spray particles was increased. The factors studied which narrow the angle of discharge also decrease the width of the ring.

The results secured indicate that the thickness of the disc is one of the most sensitive factors studied, and a very slight variation is capable of producing a very decided change in the distribution of the spray. Manufacturers have long understood that as thin a disc as possible produced the most desirable spray. For this reason they have drilled out the metal surrounding the orifice so it would be as thin as practical and yet remain strong enough to withstand wear due to the discharge of the spray material.

[22] Hewitt, J. Lee. Spraying Investigations for 1912—Arkansas Agr. Exp. Sta. Bul. 114 (1913), p. 542.

MINOR FACTORS INFLUENCING DISTRIBUTION OF SPRAY

Chief among the main factors influencing the distribution of the spray are burrs or rough places in the outlet orifice. These distort the spray in all manner of ways and are often the cause of the poor distribution of the nozzle.

Several cases were noted in which the outlet orifice was not perfectly round, but oblong in shape. In such instances, an oblong spray was discharged, and if there were no burrs or other imperfections, the material was evenly distributed in the oblong ring.

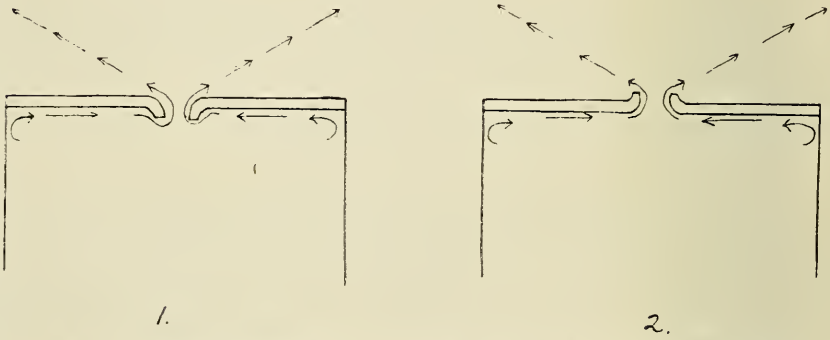

Fig. 16.—Diagram Showing How a Small Lip on the Orifice When Placed Inward (1) Interferes With the Outward Passage of the Material, but When the Disc is Reversed (2) the Rounded Edge Aids in Securing a Greater Rate of Discharge.

If the outlet orifice is not perfectly centered in the disc or if the disc fits in the cap loosely, so the orifice slips out of the center, the spray will be uneven in distribution.

Some nozzles that have a directing disc in which the supply holes have been pressed in the basal plate rather than drilled often show cracks around the hole that cause unevenness of the spray discharged.

All parts of the inside of the nozzle should be smooth, as rough places not only decrease the rate of discharge of the nozzle, but in many cases cause the distribution of the nozzle to be uneven.

SUMMARY OF FACTORS INFLUENCING DISTRIBUTION OF SPRAY

Increasing the size of the outlet orifice increases the angle of discharge, and widens the ring of spray, but so far as could be told by observation does not increase the size of the spray particles.

High pressures gave the better distribution (more perfect cones) and smallest particles. Up to a certain point the angle of the discharge was increased and the width of the ring decreased with the pressure, but the size of the spray particles became smaller as the pressure was increased.

The results indicate that for each nozzle there is an optimum pressure at which it works best, and any additional pressure results in partial loss of energy. As the depth of the eddy-chamber is increased, the angle of discharge and the width of the ring is decreased, and the size of the spray particles is increased.

The results seem to indicate that increasing the width of the eddy-chamber increases the angle of discharge and the width of the ring, and also breaks up the spray particles.

The angle at which the supply holes in the directing disc are drilled exerts a great influence on the angle of discharge, width of ring, and size of drops. The smaller the angle of the supply holes, the wider is the angle of discharge and the width of the ring, and the smaller the drops of spray. A decrease in the angle of the supply holes of fifteen degrees was found to increase the angle of discharge eight degrees in the case of the Mistry Jr. nozzle using an outlet orifice of 1.2 mm. in diameter. When the orifice was increased to 2.5 mm. the angle of discharge was increased twelve degrees.

A central supply hole in the directing disc changes the spray discharged from a hollow cone to a solid cone, narrows the angle of discharge and, in some cases, increases considerably the size of the drops.

The greater the number of supply holes at the edge of the directing disc, the greater the decrease in the angle of discharge, the narrower the width of the ring, and the larger the drops. One supply hole is not sufficient as a one-sided cone is produced. Two supply holes if located properly and of the right dimensions will produce a spray that is perfectly distributed.

The presence of a post on the directing disc decreases the angle of discharge, narrows the width of the ring, and produces a more evenly distributed spray.

A thick disc was found to reduce greatly the angle of discharge, narrow the width of the ring, and increase the size of the spray particles.

Burrs in the outlet orifice, orifices that were oblong in shape or not properly centered, discs that fitted loosely in the caps, cracks or near the holes in the directing disc, were responsible for a great deal of the imperfections found in this study since they produced an unevenly distributed spray.

DESCRIPTION OF THE SPRAY DISCHARGED BY THE NOZZLES TESTED

In the following descriptions, unless otherwise noted, the pressure was 75 pounds and the distance at which the data given were taken was 2 feet from the nozzle. Angle of discharge refers to the total angle XOZ of Fig. 17, forming the diverging sides of the cone of spray; while the width of the ring refers to the thickness of the walls, distance R to Z, Fig. 17, of the spray forming the cone.

In taking the measurements and in the descriptions much had to be left to the discretion of the writer. The distribution varied so much that approximate measurements and descriptive terms had to be used rather than more exact ones.

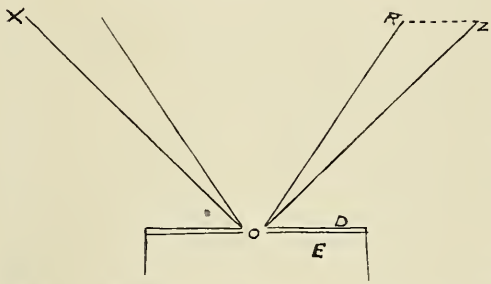

Fig. 17.—Diagram of Longitudinal Section of the Spray Discharged From a Nozzle Producing a Hollow Cone. O, Orifice; E, Eddy-chamber; D, Disc; R-Z, Width of Ring; XOZ, Angle at which Cone of Spray is Discharged.

ACME.—Sold by Deming Company, Salem, Ohio; diameter of orifice used, 2.3 mm. The discharge forms a hollow cone at an angle of about 80°; width of ring 8 inches; drops small to medium, evenly distributed; drops outside the ring numerous, small to very small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed. Nozzle may be altered to form a narrow-angled, driving spray.

ATOMIC.—Sold by E. C. Brown and Company, Rochester, N. Y. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 90°; width of ring 8 inches; drops small, much more numerous on one side than on other; drops outside the ring numerous, small to very small, unevenly distributed; drops within the ring numerous, mist-like, unevenly distributed.

AUTO SPRAY.—Sold by E. C. Brown and Company, Rochester, N. Y. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 100°; width of ring 8 inches; drops small, unevenly distributed, much more numerous on one side than on other; drops within the ring numerous, variable in size, fairly evenly distributed.

BEAN MIST.—Sold by Bean Spray Pump Company, Lansing, Mich. Diameter of orifice used 2.5 mm. The discharge forms a hollow cone at an angle of about 70°; width of ring 8 inches; drops variable in size, mostly small, unevenly distributed, more numerous on one side than on other; drops within ring numerous, mist-like, evenly distributed.

BLIZZARD.—Sold by Hardie Manufacturing Company, Hudson, Mich. Used nozzle set so discharge formed a broad fan-shaped spray; drops in center of fan variable in size, mostly large, evenly distributed; drops in edges of fan variable in size, mostly large, much less numerous than in center of fan, evenly distributed; drops outside of fan numerous, small, unevenly distributed. Nozzle may be altered to produce any gradation from solid stream to a broad fan.

BORDEAUX.—Sold by Deming Company, Salem, Ohio. Used nozzle set so discharge formed a broad, fan-shaped spray. Two-thirds of fan of the same density, drops large, evenly distributed; drops in edge of fan less numerous, smaller, evenly distributed. Nozzle may be altered to produce any gradation from solid stream to a broad fan. Distribution better than for the average Bordeaux nozzle.

Fig. 18.—Showing a Fan-Shaped Spray of Uneven Distribution. The Spray Discharged From the Bordeaux, Myers' Way, Blizzard, Caswell, and a Few Other is Similar to This.

BORDEAUX.—Sold by Hardie Manufacturing Company, Hudson, Mich. Used nozzle set so discharge formed a broad, fan-shaped spray. Drops in central half of fan large, evenly distributed; drops in edges of fan less numerous, large, evenly distributed; drops outside fan numerous, variable, evenly distributed. Nozzle may be altered to produce any gradation from solid stream to a broad fan. Distribution better than for the average Bordeaux nozzle.

BORDEAUX.—Sold by Morrill & Morley Manufacturing Company, Benton Harbor, Mich. Used nozzle set so discharge formed a broad, fan-shaped spray. Drops in center of fan large, unevenly distributed. Most of material distributed in central half of fan; drops in edges of fan less numerous, variable, smaller than in center of fan, unevenly distributed. Nozzle may be altered to produce any gradation from a solid stream to a broad fan.

CALLA.—Sold by F. E. Myers & Bro., Ashland, Ohio. The discharge is a solid stream forming a rectangle, the length being twice the width. There were two circular spots in the rectangle which covered about half of the area; drops very large, unevenly distributed; drops outside the heavier portion num-

erous, variable, unevenly distributed. The distribution of this nozzle is such that it should not be used for orchard purposes.

CALLA.—Sold by Morrill & Morley Manufacturing Company, Benton Harbor, Mich. The discharge is a solid stream forming a rectangle; drops variable, mostly large, unevenly distributed The distribution of this nozzle is such that it should not be used for orchard purposes.

CLIPPER.—Sold by Bean Spray Pump Company, Cleveland, Ohio. Used nozzle set so discharge formed a broad, fan-shaped spray. About three-fourths of the fan was of the same density, drops large, evenly distributed; drops at the edges of the fan less numerous, smaller, evenly distributed; drops outside of the fan numerous, small, evenly distributed. Nozzle may be altered to produce any gradation between solid stream and a broad fan. The distribution of this nozzle is one of the best of the Bordeaux nozzles.

CYCLONE.—Sold by Hardie Manufacturing Company, Hudson, Mich. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 75°; drops in the ring small, unevenly distributed, much more numerous on one side than on other; drops outside the ring numerous, small, unevenly distributed; drops inside the ring few, variable, unevenly distributed.

CYCLONE.—Sold by F. E. Myers & Bro., Ashland, Ohio. Diameter of orifice used 1.2 mm. The discharge forms a hollow cone at an angle of about 60°; width of ring 8 inches; drops variable, mostly very small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed. A good nozzle for very small pumps such as knapsack sprayers.

DEMOREL.—Sold by Deming Company, Salem, Ohio. Diameter of orifice used 1.7 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 8 inches, drops small, unevenly distributed, much more numerous in one half than in other; drops outside the ring numerous, small, unevenly distributed; drops inside the ring numerous, mist-like, unevenly distributed.

DEWEY.—Sold by William Stahl Manufacturing Company, Quincy, Ill. Diameter of orifice used 3.2 mm. The discharge forms a solid cone at an angle of about 52°; drops variable, mostly medium to large, unevenly distributed; drops outside the circle numerous, variable, evenly distributed.

DU SPRAY.—Sold by E. C. Brown Company, Rochester, N. Y. Diameter of orifice used 1.4 mm. The discharge forms an almost perfect hollow cone at an angle of 70°; width of ring 6 inches; drops variable, mostly very small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

EASTERN BORDEAUX.—Sold by Hayes Pump & Planter Company, Galva, Ill. Used nozzle set so discharge formed a broad, fan-shaped spray; drops in the center much more numerous than at the ends; variable, unevenly distributed; drops at ends of fan less numerous, large, but smaller than those in the center, unevenly distributed.

EUREKA.—Sold by Deming Company, Salem, Ohio. Diameter of orifice used 1.7 mm. The discharge forms a hollow cone at an angle of about 65°; width of ring 8 inches; drops variable, unevenly distributed; drops within the ring numerous, mist-like, evenly distributed. Best distribution was secured at a distance of 2 to 2½ feet from the nozzle.

EXCELALL.—Sold by Star Brass Works, Chicago, Ill. Diameter of orifice used 1.5 mm. The discharge forms almost a solid cone at an angle of about 50°; drops large, evenly distributed; drops outside the circle numerous, medium, evenly distributed.

FAR NEAR NOZZLE.—Sold by Far Near Nozzle Company, Baltimore, Md. This nozzle is made in such a way that the angle of discharge may be varied at the will of the operator from a wide angle hollow cone to a narrow angle solid cone. The hollow cone is composed of drops, variable in size, evenly distributed; drops inside the ring numerous, mist-like, evenly distributed. The solid cone is composed of large drops, evenly distributed; drops outside the ring numerous, small, evenly distributed.

FOG.—Sold by Brandt Manufacturing Company, Minneapolis, Minn. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 10 inches; drops variable, mostly small, unevenly distributed, more numerous in one half than in other; drops outside the ring numerous, small, unevenly distributed; drops within the ring numerous, mist-like, evenly distributed. This nozzle produces a fine mist spray having a good distribution.

Fig. 19.—A Hollow Cone of Spray. Most of the Nozzles of the Disc Type Distribute the Spray in This Manner.

FRIEND CALYX.—Sold by Friend Manufacturing Company, Gasport, N. Y. Diameter of orifice used 3.2 mm. The discharge forms a perfect hollow cone at an angle of about 75°; width of ring 7 inches; drops variable, evenly distributed; drops outside the ring numerous, mist-like, evenly distributed; drops within the ring numerous, mist-like, evenly distributed. This nozzle produces a driving spray which is broken into a fine mist.

FRIEND ANGLE NOZZLE AND FRIEND REGULAR.—Sold by Friend Manufacturing Company, Gasport, N. Y. Diameter of orifice used 2.8 mm. The discharge forms an almost perfect hollow cone at an angle of about 90°; width of ring 7 inches, drops variable, distribution slightly uneven, more numerous on

one side than on other; drops outside the ring numerous, mist-like, evenly distributed; drops within the ring few, mist-like, evenly distributed. These popular nozzles have been used extensively for years and are adapted to the larger spraying outfits.

GRADUATING VERMOREL.—Sold by F. E. Myers & Bro., Ashland, Ohio. Diameter of orifice used 1.2 mm. The discharge forms a hollow cone or an almost solid stream, at the will of the operator. When the discharge is a hollow cone drops small, unevenly distributed, much more numerous in one half than in other; drops outside the ring numerous, small, unevenly distributed; drops within the center very few, mist-like, evenly distributed.

IDEAL.—Sold by Brandt Manufacturing Company, Minneapolis, Minn. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 8 inches; drops variable, very unevenly distributed, one half of ring entirely gone; drops outside the ring numerous, small, evenly distributed; drops within the ring very few, mist-like, unevenly distributed.

IMPERIAL.—Sold by F. E. Myers & Bro., Ashland, Ohio. Diameter of orifice used 1.2 mm. The discharge forms a hollow cone at an angle between 50° and 60°; width of ring 8 inches; drops small, evenly distributed; drops outside the ring numerous, small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

IRON AGE.—Sold by Bateman Manufacturing Company, Grenloch, N. J. Diameter of orifice used 1.7 mm. The discharge forms a broken hollow cone at an angle of about 90°; width of ring 8 inches; drops small, unevenly distributed, one half of ring practically gone; drops outside the ring numerous, mist-like, unevenly distributed; drops within the ring very few, mist-like.

LARGE DISC.—Sold by Hayes Pump & Planter Company, Galva, Ill. Diameter of orifice used 1.8 mm. The discharge forms hollow cone at an angle of about 75°; width of ring 6 inches; drops small to medium, evenly distributed; drops outside the ring numerous, small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

LARGE DISC SOLID SPRAY.—Sold by Hayes Pump & Planter Company, Galva, Ill. Diameter of orifice used 1.8 mm. The discharge forms a solid cone at an angle of about 75°, drops variable, mostly small, evenly distributed; drops outside the circle numerous, small, evenly distributed.

LATHAM FIGURE 101.—Sold by Latham & Company, Sandusky, Ohio, Diameter of orifice used 1.5 mm. The discharge forms an almost perfect hollow cone at an angle of about 75°; width of ring 10 inches, drops variable, mostly small, evenly distributed; drops outside the ring numerous, small, evenly distributed; drops within the ring very few, mist-like.

LATHAM FIGURE 107.—Sold by Latham & Company, Sandusky, Ohio. Diameter of orifice used 2.7 mm. The discharge forms an almost perfect hol-

low cone at an angle of about 90°; width of ring 8 inches; drops variable, mostly small, evenly distributed, slightly fewer drops on one side than on other; drops outside the ring numerous, small, evenly distributed, drops within the ring very few, mist-like, evenly distributed.

LENOX.—Sold by Gould Manufacturing Company, Seneca Falls, N. Y. Diameter of orifice used 1.4 mm. The discharge forms a more or less solid cone at an angle of about 40°; drops variable, unevenly distributed; drops outside the ring numerous, small, unevenly distributed.

LITTLE CASEWELL.—Sold by Latham & Company, Sandusky, Ohio. The spray discharged forms a broad fan; drops in the center of the fan large, unevenly distributed; drops at the ends of the fan less numerous, smaller, unevenly distributed. This nozzle, like the Bordeaux, can be altered at the will of the operator to discharge any gradation between a solid stream and a broad fan.

LONG DISTANCE.—Sold by Bean Spray Pump Company, Lansing, Mich. Diameter of orifice used 1.6 mm. The discharge forms an almost perfect hollow cone at an angle of about 52°; width of ring 6 inches; drops variable, evenly distributed; drops outside the ring numerous, small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed. This nozzle has a good distribution and, as its name implies, is good for long distance spraying

MAID OF THE MIST.—Sold by H. L. Hurst Manufacturing Company, Canton, Ohio. Diameter of orifice used 1.6 mm. The discharge forms an almost solid cone at an angle of about 40°; drops variable, unevenly distributed, more numerous in some places than in others; drops outside the circle numerous, medium, evenly distributed; drops within the center very numerous, mist-like, evenly distributed. Best distribution was secured at 2½ to 3 feet.

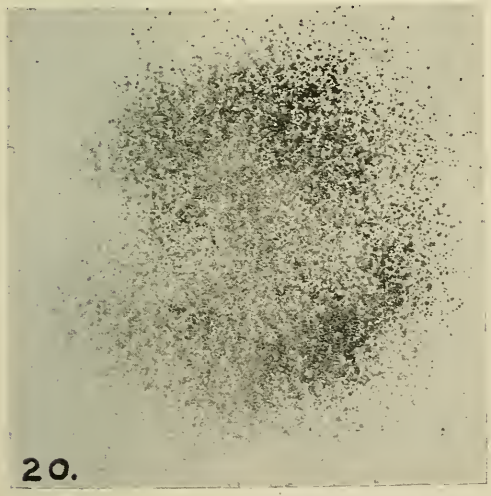

Fig. 20.—A Solid Cone of Spray. The Disc Type of Nozzle Having a Central Supply Hole in the Directing Disc Distributes the Spray in a Solid cone.

MASSO SPRAY—Sold by Crown Specialty Company, Chicago, Ill. Diameter of orifice used 2.3 mm. The discharge forms a solid cone at an angle of about 75°; drops variable, fairly evenly distributed; drops outside the circle numerous, variable, evenly distributed. Best distribution secured at 2½ to 3 feet.

MISTRY—Sold by William Stahl Manufacturing Company, Quincy, Ill. Diameter of orifice 2.5 mm. The discharge forms a

perfect hollow cone at an angle of about 75°; width of ring 7 inches; drops small, very evenly distributed; drops outside the ring numerous, mist-like, evenly distributed; drops inside the ring numerous, mist-like, evenly distributed. This nozzle has been in use several years and has been quite a favorite among orchard men.

MISTRY LARGE PATTERN.—Sold by Gould Manufacturing Company, Seneca Falls, N. Y. Diameter of orifice used 2.5 mm. The discharge forms a hollow cone at an angle of about 100°; width of ring 8 inches; drops outside the ring numerous, small, unevenly distributed; drops within the ring numerous, mist-like, evenly distributed.

MYERS POWER.—Sold by F. E. Myers & Bro., Ashland, Ohio. Diameter of orifice used 1.8 mm. The discharge forms a hollow cone at an angle of about 65°; drops in the ring variable, slightly unevenly distributed, more numerous in one half than in other; drops outside the ring numerous, small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

MYERS WAY.—Sold by F. E. Myers & Bro., Ashland, Ohio. Used the nozzle set so a broad fan was formed by the discharge; drops variable, evenly distributed over entire area. This nozzle produces a finer spray and has a better distribution than the average Bordeaux nozzle.

NEW ECLIPSE.—Sold by Morrill & Morley Manufacturing Company, Benton Harbor, Mich. Diameter of orifice used 2.0 mm. The discharge forms a hollow cone at an angle of about 75°; drops small, evenly distributed; drops outside the circle numerous, small, evenly distributed. This nozzle produces a mist-like spray and is of fairly large capacity.

NON CLOG ATOMIC.—Sold by E. C. Brown Company, Rochester, N. Y. Diameter of orifice used 2.0 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 7 inches; drops small, evenly distributed except in a few spots; drops outside the ring numerous, mist-like, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

PAINTING.—Sold by Spraymotor Company, Buffalo, N. Y. Diameter of orifice used 1.8 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 7 inches; drops variable, mostly small, evenly distributed; drops outside the ring numerous, variable, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

POWER (with disgorger).—Sold by F. E. Myers & Bro., Ashland, Ohio. Diameter of orifice used 2.0 mm. The discharge forms a hollow cone at an angle of about 70°; drops in the ring medium, evenly distributed; drops outside the ring numerous, mist-like, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

PROGRESS.—Sold by Dayton Manufacturing Company, Dayton, Ohio. Diameter of orifice used 2.0 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 7 inches; drops very small to small, evenly distributed; drops outside the ring numerous, small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed. This nozzle produced a well distributed spray at all distances tested at high and low pressure.

REGULAR CAP.—Sold by Hudson & Thurber Company, Minneapolis, Minn. Diameter of orifice used 2.0 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 8 inches; drops variable, unevenly distributed, much more numerous in one half than in other; drops outside the ring few, small, unevenly distributed; drops within the ring numerous, mist-like, evenly distributed.

SAN JOSE.—Sold by Woodin & Little, San Francisco, Cal. The spray material discharged through the slit in the elastic rubber disc forms a fan, drops large to very large, evenly distributed.

SCIENTIFIC.—Sold by Niagara Sprayer Company, Middleport, N. Y. Diameter of orifice used 1.6 mm. The discharge forms a perfect hollow cone at an angle of about 50°; width of ring 5 inches; drops variable, evenly distributed; drops outside the ring numerous, mist-like, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

SIMPLEX.—Sold by Deming Company, Salem, Ohio. Diameter of orifice used 2.0 mm. The discharge forms a perfect hollow cone at an angle of about 75°; width of ring 7 inches; drops small, evenly distributed; drops outside the ring numerous, very small to small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed. This nozzle produces a spray that is well distributed and is adapted for hand and power sprayers.

SINGLE VERMOREL.—Sold by F. E. Myers & Bro., Ashland, Ohio. Diameter of orifice used 1.2 mm. The discharge forms a hollow cone at an angle of about 70°; width of ring 7 inches; drops small, unevenly distributed, one half of ring practically gone; drops outside the ring numerous, small, unevenly distributed; drops within the ring few, mist-like, unevenly distributed.

SINGLE VERMOREL.—Sold by Morrill & Morley Manufacturing Company, Benton Harbor, Mich. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 55°; width of ring 8 inches; drops variable, unevenly distributed, much more numerous in one half than in other; drops outside the ring few, unevenly distributed; drops within the ring numerous, mist-like, unevenly distributed, most numerous next to heaviest portion of ring.

SINGLE VERMOREL.—Sold by Field Force Pump Company, Elmira, N. Y. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an

angle of about 70°; width of ring 7 inches; drops variable, unevenly distributed, one half of ring almost entirely gone; drops outside the ring numerous, small, unevenly distributed; drops within the ring numerous, mist-like, evenly distributed.

SIX IN ONE ANY ANGLE.—Sold by Gifford Manufacturing Company, Barker, N. Y. Diameter of orifice used 1.6 mm. The discharge forms an almost perfect hollow cone at an angle of about 80°; width of ring 6 inches; drops mostly small, evenly distributed; drops outside the ring numerous, small, evenly distributed, drops within the ring very few, mist-like. This nozzle has a good distribution and produces a mist-like spray.

SMALL SIZED MISTRY.—Sold by Gould Manufacturing Company, Seneca Falls, N. Y. Diameter of orifice used 1.4 mm. The discharge forms a hollow cone at an angle of about 55°; drops small, unevenly distributed, more numerous in three-fourths of the ring; drops outside the ring numerous, small, unevenly distributed; practically no drops within the ring.

SPECIAL SINGLE VERMOREL.—Sold by Field Force Pump Company, Elmira, N. Y. Diameter of orifice 1.2 mm. The discharge forms a hollow cone at an angle of about 50°; width of ring 8 inches; drops variable, mostly small, unevenly distributed, much more numerous in one half than in other; drops outside the ring numerous, small, unevenly distributed; drops within ring numerous, mist-like to very small; unevenly distributed.

SPRAMIST.—Sold by Deming Company, Salem, Ohio. The Spramist and Tiger Strainer nozzles are the same, only put out under different names.

SPRAY MOTOR FIGURE 56.—Sold by Spraymotor Company, Buffalo, N. Y. Diameter of orifice used 2.0 mm. The discharge forms an almost perfect hollow cone at an angle of about 60°; width of ring 8 inches; drops variable, mostly small, evenly distributed; drops outside the ring numerous, small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

SPRINKLE.—Sold by F. E. Myers & Bro., Ashland, Ohio. The discharge is a solid stream at a narrow angle, drops large, unevenly distributed.

SULPHUR.—Sold by Woodin and Little, San Francisco, Cal. Diameter of orifice used 1.0 mm. The discharge forms a perfect hollow cone at an angle of about 45°; width of ring 5 inches; drops variable, mostly small, evenly distributed; drops outside the ring few, small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

TIGER STRAINER.—Sold by Field Force Pump Company, Elmira, N. Y. Diameter of orifice used 2.0 mm. The discharge forms a hollow cone at an angle of about 90°; width of ring 8 inches; drops very small to small, unevenly distributed, more numerous in one half of ring than in other; drops outside the ring numerous, mist-like, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

VAPO.—Sold by Hardie Manufacturing Company, Hudson, Mich. Diameter of orifice used 1.9 mm. The discharge forms a hollow cone at an angle of about 90°; width of ring 9 inches; drops very small to small, unevenly distributed, more numerous in some spots than in others; drops outside the ring numerous, very small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

VAPO MIST.—Sold by Field Force Pump Company, Elmira, N. Y. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 8 inches; drops variable, mostly small, evenly distributed; drops outside the ring numerous, small to very small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed

VERMOREL.—Sold by Bean Spray Pump Company, Lansing, Mich. Diameter of orifice used 1.5 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 7 inches; drops variable, mostly small, unevenly distributed, more numerous in spots; drops outside of the ring numerous, small, fairly evenly distributed; drops within the ring numerous, mist-like, evenly distributed.

VERMOREL.—Sold by E. C. Brown Company, Rochester, N. Y. Diameter of orifice used 1.6 mm. The discharge forms almost a solid cone at an angle of about 90°; drops very small to small, slightly unevenly distributed, more numerous in one side than in other; drops outside the circle numerous, small, evenly distributed. A good nozzle of this type.

VERMOREL.—Sold by Deming Company, Salem, Ohio. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 90°; width of ring 7 inches; drops small, unevenly distributed; much more numerous in one half than in other; drops outside the ring numerous, variable, unevenly distributed. Practically no drops within the ring.

VERMOREL.—Sold by Hardie Manufacturing Company, Hudson, Mich. Diameter of orifice used 1.6 mm. The discharge forms a hollow cone at an angle of about 75°; width of ring 7 inches; drops small, unevenly distributed, much more numerous in one half than in other; drops outside the ring few, mist-like, unevenly distributed; drops within the ring numerous, mist-like, evenly distributed.

VERMOREL.—Sold by Spraymotor Company, Buffalo, N. Y. Diameter of orifice used 1.5 mm. The discharge forms a perfect hollow cone at an angle of about 70°; width of ring 8 inches; drops small to mist-like, evenly distributed; drops outside the ring numerous, small, evenly distributed; drops within the ring numerous, mist-like, evenly distributed. A very good nozzle of the Vermorel type.

VERMOREL-DAYTON.—Sold by Dayton Manufacturing Company, Dayton, Ohio. Diameter of orifice used 2.0 mm. The discharge forms a hollow cone at an angle of about 55°; drops variable, unevenly distributed, much more numerous in three spots; drops within the ring so numerous that discharge may be classed as a solid cone, variable, unevenly distributed.

WESTERN BORDEAUX.—Sold by Hayes Pump & Planter Company, Galva, Ill. Used nozzle set so discharge formed a broad, fan-shaped spray. Drops much more numerous in central third of fan, large, unevenly distributed; drops at each end of fan less numerous than in center, smaller in size, unevenly distributed.

WHIRLPOOL.—Sold by Bean Spray Pump Company, Lansing, Mich. Diameter of orifice used 1.6 mm. The discharge forms a solid cone at an angle of about 45°; drops variable, slightly unevenly distributed, more numerous in one side than in other; largest drops at outer edge of cone, smallest in the center; as a whole distribution good.

Capacity of Spray Nozzles and Factors Governing Their Rate of Discharge

APPARATUS USED

In this work numerous difficulties were encountered in securing an even and uniform pressure. A double-action hand pump with a pressure gauge on the pump and another just in the rear of the nozzle was first used, but the pressure was found to vary from five to ten pounds with nozzles of small capacity and more with the larger nozzles. To overcome this a specially constructed tank with spigot and tight fitting cover was then connected to a two-inch water main. The arrangement of this apparatus is shown in Fig. 21. A pressure gauge was placed as close the nozzle as possible and just in rear of this was a cut-off valve. The pressure still varied with nozzles of different capacity, but by placing a second valve back of the first and adjusting this to the flow through each individual nozzle an absolute pressure could be maintained.

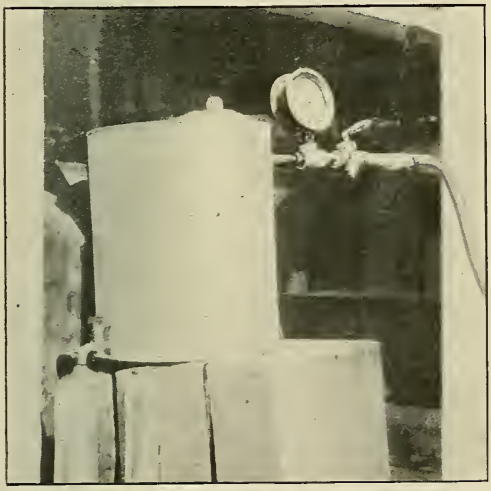

Fig. 21.—Apparatus Used in Securing the Results on Rate of Discharge.

The same nozzles were used in this test as in the distribution study. As before, the different dimensions of the nozzles were changed by substituting parts from other nozzles or by making new ones so that a study of the factors governing the rate of discharge could be made.

METHOD OF MAKING A TEST

After the nozzle to be tested was in place, the valves were opened and the rear one adjusted to produce the desired pressure. Then the valve just in the rear of the pressure gauge was closed and the tank drained. To make a test this valve was opened and the nozzle was allowed to play for two minutes, timed with a stop-watch. The liquid

was then drawn from the tank and measured in graduates in terms of cubic centimeters. Triplicate tests were made of each nozzle and the average of these was used in all computations.

INFLUENCE OF OUTLET ORIFICE ON RATE OF DISCHARGE

The diameter of the outlet orifice was found to have the greatest influence on the rate of discharge of any of the factors studied. But orifice diameter or area is not the only factor influencing capacity, and taken alone affords no index of the rate of discharge of a nozzle. This fact is well illustrated in Table 8, where nozzles of similar size, appearance, and construction show a wide variation in capacity with an orifice of the same size. For example a difference of 138.5 liters was found in the rate of discharge between the Friend Regular and the Friend Calyx nozzles, both having an outlet orifice diameter of 3.2 mm. If the orifice diameter were a good basis for rating the discharge of the nozzles, it would be expected that nozzles having the same size orifice would have practically the same discharge. That this is not a good basis for rating capacity is indicated by a comparison of Friend Calyx and Tiger Strainer nozzles with a 2.0 mm. orifice. The capacity of the former is practically double that of the latter. It is true that the size of the orifice is the most important factor governing the rate of discharge, but there are so many other things influencing capacity that no formula can be made for calculating the rate of discharge for any nozzle, at a given pressure, with a certain orifice.

Increasing the size of the outlet orifice was found to increase the total discharge of the nozzle, but when the volume discharged is calculated in liters per square millimeter of orifice area, the rate of discharge per sq. mm. is decreased. The Friend Angle nozzle having an orifice of 3.1416 sq. mm. gave a discharge of 53.41 liters per sq. mm. When the orifice was increased to 6.1575 sq. mm. the discharge was 42.90 liters per sq. mm., thus representing a loss of 10.51 liters per sq. mm. in the rate of discharge. An orifice of 8.0425 sq. mm. gave 39.42 liters per sq. mm. or 13.99 liters less than when the orifice was 3.1416 sq. mm. Even more pronounced is the loss in the case of the Tiger nozzles.

Thus the conclusion can be drawn that an increase in the area of the outlet orifice increases the total discharge but does not give an increase corresponding to the increase in area. As the size of the orifice was increased, some nozzles approached more nearly a corresponding increase in discharge than did others. The Non Clog Atomic

TABLE 8.—Influence of Outlet Orifice on Rate of Discharge.

NOZZLE	Diameter of Orifice in mm.	Area of Orifice in sq. mm.	Discharge in Liters, 50 lbs. Pressure	Rate of Discharge per sq. mm.	Decrease in Rate of Discharge per sq. mm.
Friend Angle*___	2.0	3.1416	167.8	53.41	
Friend Angle*___	2.8	6.1575	264.2	42.90	10.51
Friend Angle*___	3.2	8.0425	317.1	39.42	13.99
Friend Calyx*___	2.0	3.1416	195.5	62.22	
Friend Calyx*___	2.8	6.1575	322.9	52.44	9.78
Friend Calyx*_	3.2	8.0425	405.2	50.38	11.84
Friend Regular*	2.0	3.1416	150.5	47.90	
Friend Regular*	2.8	6.1575	220.7	35.84	12.06
Friend Regular*	3.2	8.0425	266.7	33.16	14.74
Non Clog Atomic_	1.2	1.131	57.0	50.39	
Non Clog Atomic_	1.8	2.5447	114.8	45.11	5.28
Non Clog Atomic_	2.2	3.8013	155.7	40.95	9.44
Spramist**_____	1.2	1.131	59.1	52.25	
Spramist**_____	1.6	2.0106	87 9	43.71	8.54
Spramist**_____	2.0	3.1416	123 3	39.24	13.01
Tiger (Angle)**_	1.2	1.131	54.3	48.01	
Tiger (Angle)**_	1.6	2.0106	74.4	37.00	11.01
Tiger (Angle)**_	2.0	3.1416	95.2	30.30	17.71
Tiger (straight)**	1.2	1.131	55.4	48.98	
Tiger (straight)**	1.6	2.0106	77.4	38.49	10.49
Tiger (straight)**	2.0	3.1416	102.4	32.59	16.39

having an outlet orifice of 1.131 sq. mm. gave a discharge of 50.39 liters per sq. mm., but when the orifice was increased to 3.1416 sq. mm. a discharge of only 42.78 liters per sq. mm. was obtained or a loss of 7.61 liters under the rate of the smaller orifice (not shown in Table 8). In the case of the Tiger (straight) nozzle a loss of 16.39 liters per sq. mm. was secured under the same conditions (Table 8, columns 3 and 5).

As will be pointed out later, a number of factors including depth, and width of eddy-chamber, and the number, position and angle of supply holes exert more or less influence on the capacity and hence increase or decrease the effect of the orifice. Presumably the reason why an increase in the area of the outlet orifice does not give a corresponding increase in the discharge is that there is not sufficient supply back of the orifice to provide for the greater area. There is also a very good indication that the spray material passing out of the orifice does not completely fill it. Undoubtedly the material rolls out over the edges of the orifice and very little if any is present

* The three Friend Nozzles are alike in every respect, except the supply holes in the directing disc. The same discs were used in all three nozzles.

** Spramist and Tiger Nozzles are alike in practically every respect and the same discs were used in making these tests on all three nozzles.

in the center. This would explain the smaller rate of discharge for each square millimeter as the size of the orifice is increased.

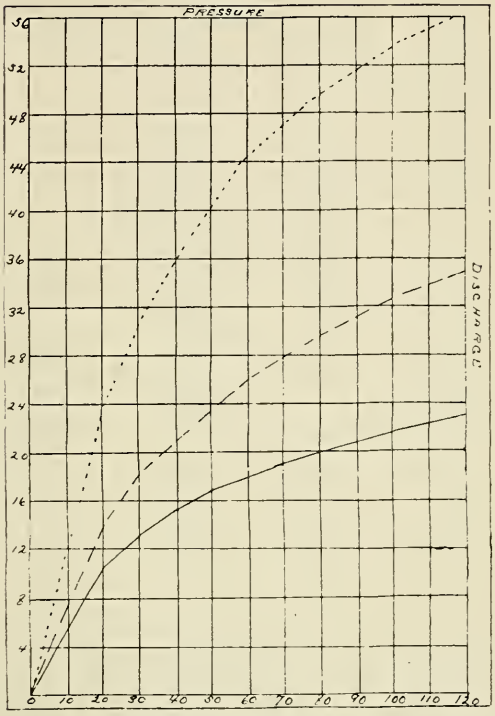

Fig. 22.—Influence of Pressure on Rate of Discharge. Solid Line Represents Discharge of Atomic Nozzle, Diameter of Orifice 1.2 mm. Broken Line Indicates Discharge of Fog Nozzle, Diameter of Orifice 1.6 mm. Dotted Line Indicates the Discharge of Tiger Strainer Nozzle, Diameter of Orifice 2.0 mm.

THE EFFECT OF PRESSURE ON RATE OF DISCHARGE

Three different nozzles, each having a different sized orifice, were tested at 10 pound intervals and at pressures ranging from 10 to 120 pounds. The results obtained show that the curves for rate of discharge of the three nozzles rise rapidly at first, and then slow up (Fig. 22). In other words for each additional ten pounds pressure a smaller increase in rate of discharge was obtained. A study of this increase in rate of discharge shows that when the pressure is doubled the total volume discharged is increased 1.4 times. This rule is not infallible, but is reasonably accurate in most cases. Two other nozzles were tested in the same way with similar results.

The usual method for reckoning discharge at any pressure does not apply to nozzles of the eddy-chamber type. When the volume discharged for the different pressures is squared and a curve plotted, it is not a straight line (Fig. 23) and it does not pass through the orgin. Hence the formula *V = *radical* (KxP) cannot be used. The approximate ratio of 1.4 increase for doubling pressure will aid materially in the selection of nozzles suitable for the work to be performed, and in proper relation to the size or capacity of the spraying outfit to be used.

* The formula V = *radical* (K x P) is used to determine the numerical progression of a straight curve. V equals velocity or rate of discharge. K equals slopes or angles of the straight curve, and P equals pressure.

INFLUENCE OF DEPTH OF EDDY-CHAMBER ON RATE OF DISCHARGE

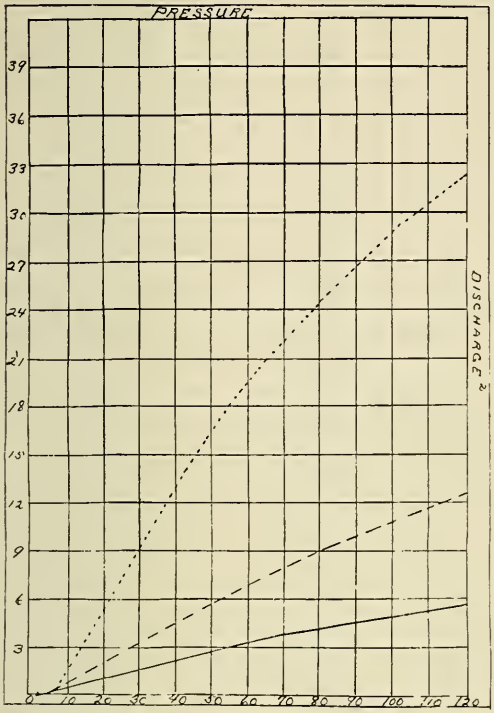

Fig. 23.—Showing that the Discharge Curves of Fig. 22 Are Not Square Curves and do not Pass Through the Point of Origin.

It has been known for some time that increasing the depth of the eddy-chamber increases the rate of discharge. Hewitt[23] found that by increasing the depth of the eddy-chamber from one-eighth to one-fourth inch an increase of one-sixth of the total volume discharged was secured.

The results obtained in this study show that this is true in most cases. A few exceptions, however, were found in which the deeper eddy-chamber gave a decreased rate of discharge. This was particularly true of the Scientific nozzle, using an orifice of 1.6 mm. when the depth of the eddy-chamber was changed from 2.5 mm. to 5.0 mm. a decrease in the rate of discharge of 2.7 liters was obtained. When the depth was increased to 7.5 mm., the decrease over the discharge at 5.0 mm. was only .3 liters or 3.0 liters over the discharge when the depth was 2.5 mm. The same thing held true during the series of tests with the 2.3 mm. orifice. Judging from these figures there is an indication that should the depth of the eddy-chamber be sufficiently increased a point would be reached when the nozzle would stop showing a decrease. A few other nozzles similar in construction to the Scientific gave a decreased rate of discharge. When the depth of the eddy-chamber in these nozzles was increased the spray was discharged in uneven spurts, sounding as though there was air in the spray material; apparently this uneven flow decreased the total volume discharged.

The majority of the disc nozzles studied gave an increased rate of discharge when the eddy-chamber was made deeper. This greater

[23] Hewitt, J. Lee, Spraying Investigations for 1912—Arkansas Agr. Exp. Sta. Bul. 114 (1913).

TABLE 9.—Influence of Depth of Eddy-chamber on Rate of Discharge

NOZZLE	Diameter of Orifice in mm.	Depth of Eddy-chamber in mm.	Discharge, 50 lbs. Pressure, in Liters per Hr.	Gain in Liters for Increased Depth of Chamber	Gain in Liters for each mm. Increased depth
Fog*	1.6	2.5	103.9		
Fog*	1.6	4.5	106 6	2.7	1.35
Scientific*	1.6	2.5	133.8		
Scientific*	1.6	5.0	131.1	−2.7	−1.08
Scientific*	1.6	7.5	130.8	−3.0	−.6
Scientific*	2.3	2.5	256.8		
Scientific*	2.3	5.0	252.3	−4.5	−1.80
Scientific*	2.3	7.5	251.4	−5.4	−1.08
Tiger Strainer	1.2	3.0	55.4		
Tiger Strainer	1.2	6.0	56.7	1.3	.43
Tiger Strainer	1.6	3.0	75.3		
Tiger Strainer	1.6	6.0	77.7	2.4	.8
Tiger Strainer	2.0	3.0	102.4		
Tiger Strainer	2.0	6.0	104.3	1.9	.63
Tiger Strainer**	1.2	3.0	65.4		
Tiger Strainer**	1.2	6.0	67.2	1.8	.6
Tiger Strainer**	1.6	3.0	94.8		
Tiger Strainer**	1.6	6.0	96.9	2.1	0.7
Tiger Strainer**	2.0	3.0	121.8		
Tiger Strainer**	2.0	6.0	126.9	5.1	1.70
New Eclipse	2.0	3.5	170.5		
New Eclipse	2.0	6.7	177.3	6.8	2.12
New Eclipse	2.8	3.5	252.9		
New Eclipse	2.8	6.7	264.4	11.5	3.59
Iron Age	1.7	3.7	74 8		
Iron Age	1.7	6.5	75.6	.8	.28
Iron Age	2.0	3.7	93.2		
Iron Age	2.0	6.5	96.1	2.9	1.03

rate of discharge varied with the increase in depth of the eddy-chamber and with the size of the orifice; the larger the orifice the greater the increase. This is well illustrated in the case of the New Eclipse nozzle (Table 9). When the outlet orifice was 2.0 mm. and the depth of the eddy-chamber was increased from 3.5 mm. to 6.7 mm. an increased discharge of 6.8 liters or 2.12 liters for each millimeter of added depth was secured. When an orifice of 2.8 mm. was used, an increased discharge of 11.5 liters or 3.59 liters for each millimeter of added depth was obtained. By using the larger orifice the deeper eddy-chamber was able to discharge 1.47 liters more for each millimeter the depth of the eddy-chamber was increased than when the smaller orifice was used.

* Tests were made at 100 pounds pressure on the Fog and Scientific nozzles with similar results.

** Same nozzle but with the area and angle of the supply holes changed.

As to why some of the nozzles studied should give a greater rate of discharge with a deeper eddy-chamber and others give a decrease is hard to explain satisfactorily. The indications are that when the angle at which the supply holes pass through the directing disc is as small as 10 degrees or less the liquid is whirled so violently that a very shallow eddy-chamber must be used in order that the spray will be discharged in an even mist. In the case of a nozzle of this kind any increase in the depth of the eddy-chamber would tend to upset the equilibrium of the nozzle by causing conflicting currents that would retard and break up the outward passage of the material in a spiral or conical motion. In this way the spray is discharged in uneven spurts until the equilibrium of the nozzle is re-established. Nozzles having the supply holes in the directing disc at an angle of 35 degrees or more did not show these results as the spray material was flowing more nearly in a line with the hose.

INFLUENCE OF WIDTH OF THE EDDY-CHAMBER ON RATE OF DISCHARGE

Hewitt [24] found that the width of the eddy-chamber exerted very little influence on the rate of discharge of the disc spray nozzles. The results obtained in this study show that the width of the eddy-chamber

TABLE 10.—Influence of Width of the Eddy-chamber on the Rate of Discharge.

NOZZLE	Diameter of Orifice in mm.	Width of Eddy-chamber in mm.	Discharge, 50 lbs. Pressure, in Liters per Hour	Gain in Liters for Wider Eddy-chamber	Gain in Liters for Each mm. Increased Width
Friend Regular	2.0	25.0	150.5		
Friend Regular	2.0	26.0	152.1	1.6	1.6
Friend Regular	2.8	25.0	220.7		
Friend Regular	2.8	26.0	221.9	1.2	1.2
Friend Regular	3.2	25.0	266.67		
Friend Regular	3.2	26.0	267.2	0.53	0.53
Spramist	1.2	20.0	59.1		
Spramist	1.2	22.0	59.1	0.0	0.0
Spramist	1.6	20.0	83.4		
Spramist	1.6	22.0	87.9	4.5	2.25
Spramist	2.0	20 0	121.2		
Spramist	2 0	22.0	123.3	2.1	1.05

is not as important a factor as are some other parts of the nozzle. In the case of the nozzles tested, widening the eddy-chamber increased the rate of discharge (Table 10). The increase in total volume dis-

[24] Hewitt, J. Lee, Spraying Investigations for 1912—Arkansas Agr. Exp. Sta. Bul. 114 (1913).

charged per millimeter greater width or depth is about the same, as is shown by a comparison of Tables 9 and 10. This fact indicates that the width and depth of the eddy-chamber have about the same influence on the rate of discharge. A study of Table 10 indicates that the width of the eddy-chamber exerts its greatest influence upon the capacity of the nozzle when a small orifice is used, and as the orifice is made larger this influence is overcome. This is the reverse of what was found in connection with the influence of the depth of the eddy-chamber.

Owing to the machinery needed to drill new directing discs with the supply holes in the desired position, the effect of a greater increase than two millimeters in the width of the eddy-chamber could not be determined. New directing discs were needed, as a large washer would cover up the supply holes or a narrower one would make an offset between the edge of the hole and the edge of the washer and thus destroy some factor influencing the rate of discharge.

It seems reasonable to expect an increase in the rate of discharge by increasing the diameter of the eddy-chamber for the very evident reason that as the diameter is increased the more angles there are at which the spray material may enter the outlet orifice. This could only be true to a certain point and beyond that no increase in rate of discharge would be obtained.

In most cases an increase in the depth of the eddy-chamber gave an increase in the rate of discharge. In the opinion of the writer, this may be partially explained in the same way as the increase secured when the eddy-chamber was made wider. As the disc nozzles have a very shallow eddy-chamber an increase in depth would increase the angles at which the whirling spray material might enter the orifice.

INFLUENCE OF AREA OF SUPPLY HOLES IN THE DIRECTING DISC ON THE RATE OF DISCHARGE

The rate of discharge of the disc spray nozzles may be increased by using a larger area of supply holes. On the average, each square millimeter added to the area of the supply holes increased the rate of discharge about two liters. A study of the accompanying table (Table 11) shows that in the case of the Friend nozzles using an outlet orifice of 2.0 mm. in diameter when the area of the supply holes was increased three times a gain of 45.0 liters was secured for the greater area, or .89 liters gain was secured for each additional square millimeter added to the area of the supply holes. When an orifice of 2.8 mm. in diameter was used under the same conditions an increase of 102.2 liters was obtained or 2.03 liters for each square millimeter the area of the supply holes was increased. A gain of 138.5 liters was secured when an orifice of 3.2 mm. in diameter was used under the

TABLE 11.—Influence of Area of Supply Holes in Directing Disc on Rate of Discharge.

NOZZLE	Diameter of Orifice in mm.	Area of Supply Holes in sq. mm.	Discharge, 50 lbs. Pressure, in Liters per Hour	Gain in Liters for Greater Area	Gain in Liters per sq. mm. Greater Area
Friend Regular*	2.0	25.1328	150.5		
Friend Calyx	2.0	75.3984	195.5	45.0	.89
Friend Regular	2.8	25.1328	220.7		
Friend Calyx	2.8	75.3984	322.9	102.2	2.03
Friend Regular	3.2	25.1328	266.7		
Friend Calyx	3.2	75.3984	405.2	138.5	2.75
Simplex**	1.6	12.5664	100.4		
Simplex**	1.6	25.1328	124.1	23.7	1.88
Simplex	2.0	12.5664	128.1		
Simplex	2.0	25.1328	162.0	33.9	2.69

same conditions as before or a greater discharge of 2.75 liters for each square millimeter added to the area of the supply holes. This shows that as the size of the outlet orifice is enlarged the influence of the greater area of its supply holes becomes more marked. This is to be expected, for it is obvious that when the orifice is small a small supply hole will come nearer furnishing a sufficient amount of liquid to give a maximum discharge than would be the case with a large orifice. Hence, the larger orifice simply provides a condition that works the larger area of supply holes more nearly to capacity.

INFLUENCE OF POSITION OF SUPPLY HOLES ON RATE OF DISCHARGE

A study of the accompanying table (Table 12) shows very clearly that the addition of a small vertical hole in the center of the directing disc increases the capacity of the nozzle to a marked degree. This increase is entirely out of proportion to the size of the hole and leads at once to the conclusion that the gain in rate of discharge is due not so much to a small addition to the area of the supply holes, but to the fact that it makes possible a more effective grouping of the currents passing through the outlet orifice. To point this out more in detail, it was found that the maximum increase in the rate of discharge obtained for each square millimeter added to the area of the supply holes at the edge of the directing disc was 2.75 liters (Table 11.) When a small vertical hole was placed in the center of the directing disc an increase in the rate of discharge of as much as 49.07 liters was secured for a square millimeter added to the area of the supply holes (Table

* The Friend Regular nozzle has two supply holes 4.0 mm. in diameter, while the Friend Calyx has six. Both nozzles are alike in every other respect.

** In making the tests with this nozzle one of the two oblique holes in the directing disc was plugged with a piece of soft wood.

TABLE 12.—Influence of Position of Supply Holes on the Rate of Discharge.

Nozzle	Diameter of Orifice in mm.	Number and Position of Supply Holes				Area of Supply Holes in sq. mm.	Discharge in Liters per Hour	Increase in Liters for Center Hole	Increase in Liters for Each sq. mm. of Center hole
		Edge		Center					
		No.	Dia. in mm.	No.	Dia. in mm.				
New Eclipse__	2.0	2	3.6	0	0.0	20.357	127.9		
New Eclipse__	2.0	2	3.6	1	1.2	21.488	170.5	42.6	37.66
New Eclipse__	2.8	2	3.6	0	0.0	20.357	197.4		
New Eclipse__	2.8	2	3.6	1	1.2	21.488	252.9	55.5	49.07
Masso Spray__	2.0	2	3.9	0	0.0	23.89	158.0		
Masso Spray__	2.0	2	3.9	1	2.5	28.799	209.4	51.4	10.47
Masso Spray__	2.8	2	3.9	0	0.0	23.89	216.4		
Masso Spray__	2.8	2	3.9	1	2.5	28.799	307.5	91.1	18.56
Whirlpool ____	1.6	2	5.0	0	0.0	39.27	141.9		
Whirlpool ____	1.6	2	5.0	1	1.2	40.401	143.4	1.5	1.32

12). Judging from the results secured, if the total area of the supply holes at the edge of the directing disc is large and the outlet orifice is small, a central supply hole will not have so marked an effect. This is shown in Table 12 for the nozzles tested. The New Eclipse nozzle having a larger orifice than the Whirlpool but having a smaller area of supply holes gave the greatest increase in rate of discharge upon the addition of the central supply holes.

The increase in the rate of discharge due to the central supply hole was found to become greater as the size of the outlet orifice was increased. For example, the New Eclipse nozzle having an orifice of 2.0 mm. in diameter gave a greater discharge of 42.6 liters as a result of the central supply hole 1.2 mm. in diameter being used in addition to the outer holes. However, when the orifice was increased to 2.8 mm. in diameter an increased rate of discharge of 55.5 liters was secured (Table 12). More marked results were secured in the case of the Masso Spray nozzle under the same conditions. This added increase due to the larger orifice is to be expected for the same reasons that were put forth under the heading of influence of area of supply holes on the rate of discharge.

The explanation as to why a small vertical hole in the center of the directing disc exerts such a marked influence may be readily understood when it is remembered that this hole changes the character of the spray discharged from a hollow to a solid cone (Tables 4 and 6), thus filling up the center of the cone and thereby increasing the discharge. In a nozzle discharging a hollow cone shaped spray the currents must whirl around the outer edge of the eddy-chamber and pass out around the edge of the outlet orifice in a whirling motion. Then when a small vertical hole is also placed in the directing disc the material passing through it travels in a straight line through the center of the outlet orifice without entirely destroying the effect of the supply holes at the edge of the basal plate or directing disc. It will be re-

membered that the central supply hole narrowed the angle of spray so it must tend to pull the spray material that is being discharged around the edge of the outlet orifice together thus causing the current that is flowing through the center of the orifice to be broken up into a mist and increasing the rate of discharge by filling the central part of the orifice.

INFLUENCE OF ANGLE OF SUPPLY HOLES ON THE RATE OF DISCHARGE

The angle of the supply holes was found to have considerable influence on the capacity of the nozzle. A nozzle having the supply holes at an angle of 60 degrees will have a greater rate of discharge than will a nozzle having the supply holes at an angle of 45 degrees, other conditions being equal. For example, the Mistry nozzle having an orifice of 2.5 mm. in diameter discharged 55.8 liters more per hour when the supply holes were at an angle of 60 degrees than when they were at 45 degrees (Table 13). For each degree the angle of the

TABLE 13.—Influence of Angle of Supply Holes on the Rate of Discharge.*

Nozzle	Diameter of Orifice in mm.	No.	Dia. in mm.	Supply Holes. Area in sq. mm.	Angle in Degrees	Discharge in Liters per Hour	Gain in Liters for Greater Angle	Gain in Liters for Each Degree Greater Angle
Tiger Strainer---	1.2	2	2.8	12.315	45	54.4		
Tiger Strainer---	1.2	1	3.2	8.0425	60	65.4	11.0	0.73
Tiger Strainer---	1.6	2	2.8	12.315	45	75.3		
Tiger Strainer---	1.6	1	3.2	8.0425	60	96.9	21.6	1.44
Tiger Strainer---	2.0	2	2.8	12.315	45	102.4		
Tiger Strainer---	2.0	1	3.2	8.0425	60	121.8	19.4	1.29
Friend Angle----	2.0	2	4.5	31.8087	45	167.8	17.3	1.73
Friend Regular--	2.0	2	4.0	25.1328	35	150.5		
Friend Angle----	2.8	2	4.5	31.8087	45	264.2	43.5	4.35
Friend Regular--	2.8	2	4.0	25.1328	35	220.7		
Friend Angle----	3.2	2	4.5	31.8087	45	317.1	50.4	5.04
Friend Regular--	3.2	2	4.0	25.1328	35	266.7		
Mistry Jr.-------	1.2	2	2.8	12.315	45	64.5		
Mistry ----------	1.2	2	2.8	12.315	60	76.2	11.7	0.78
Mistry Jr.-------	2.5	2	2.8	12.315	45	127.4		
Mistry ----------	2.5	2	2.8	12.315	60	182.1	54.7	3.64
Mistry ----------	2.5	2	2.8	12.315	45	126.3	55.8	3.72

* From first inspection of Table 13 it would appear that there are other factors present which would have more or less influence on the results. This is true in the case of the Tiger Strainer and Friend nozzles. In the former the increase due to the straighter supply holes was less than it really should have been due to a smaller area of supply holes. In the latter nozzles the supply holes having the widest angle had also a slightly greater area but this increase in area was not sufficient to account in full for the increased discharge. With the Mistry nozzle the gain due to the wider angle is probably slightly diminished by reason of a 90 degree angle in the shank of the nozzle.

supply holes were increased a greater discharge of 3.72 liters was obtained. The other nozzles included in Table 13 had some other dimension changed as well as the angle of the supply holes (see footnote), so the results can only be interpreted as to what influence the angle of the supply holes have under these conditions.

As has been true in so many other cases, the gain due to increased angle of the supply holes becomes greater as the size of the orifice is enlarged (Table 13, columns 2 and 8). There is an indication, however, that a point would soon be reached where this would not be true, as is illustrated by the Tiger Strainer nozzle. When the orifice used was 1.2 mm. in diameter a greater discharge of 11.0 liters was obtained due to the supply holes being at a 15 degree greater angle. Under the same condition a gain of 21.6 liters was secured for an orifice of 1.6 mm. in diameter. But when the orifice was increased to 2.0 mm. in diameter an increase of only 19.4 was obtained, showing that the supply was still not great enough to work the orifice to its greatest limit.

The reason for an increase in the rate of discharge of the spray nozzles when the supply holes are at a greater angle is that as the holes become more nearly parallel to the line of discharge the amount of friction and loss of pressure is reduced. The spray material does not lose so much of its energy against the side walls of the eddy-chamber and has a more uninterrupted outward passage, thus increasing the volume discharged. As the angle of the spray is narrowed by using supply holes at a greater angle the whirling of the material in the eddy-chamber must be less violent, which would, perhaps, also increase the capacity of the nozzle.

INFLUENCE OF A POST ON THE DIRECTING DISC ON THE RATE OF DISCHARGE

As has been stated before, "post" is a term applied by the writer to a projection located in the center of the directing disc. Only a few nozzles have this feature embodied in them. When a post was used on the directing disc it was found to increase the rate of discharge. In the case of the Whirlpool nozzle a gain of 6.9 liters per hour was obtained (Table 14).

The reason for the increased discharge of the nozzles when a post is used may be explained when it is considered that the angle of the spray was narrower and the distribution of the particles was more even and compact. Then it must be considered that anything that tends to cause the material to whirl in an even stream without conflicting currents in the eddy-chamber would certainly increase the volume of material discharged.

Table 14.—Influence of Post on Directing Disc on the Rate of Discharge.

NOZZLE	Diameter of Orifice in mm.	Discharge in Liters per Hour, 50 Pounds Pressure	Difference in Liters
Whirlpool----------	1.6 (Without post)	136.5	
Whirlpool*----------	1.6 (With post)	143.4	6.9

INFLUENCE OF THICKNESS OF DISC ON THE RATE OF DISCHARGE

Very little work was done on the influence of thickness of the disc as it was so evident that the discharge varies inversely with its thickness. This is well illustrated in Table 15, where so small a difference as .5 mm. was found to increase the capacity of the nozzle 1.5 liters. A thick disc tends to contract the vein or stream at some point as it is passing out, causing a smaller rate of discharge.

TABLE 15.—Influence of Thickness of the Disc on the Rate of Discharge.

NOZZLE	Diameter of Orifice in mm.	Thickness of Disc in mm.	Discharge in Liters Per Hour, 50 lbs. Pressure	Gain in Liters
Painting--	1.8	1.0	126.9	
Painting--	1.8	0.5	128.4	1.5

INFLUENCE OF A 45-DEGREE ANGLE ON THE RATE OF DISCHARGE

An angle on the nozzle reduces the volume of material discharged by increasing friction; and the larger the orifice or the more material that is being discharged, the greater the loss due to more friction (Table 16). Manufacturers of nozzles have overcome this in several ways. They have made the supply holes in the angle nozzle larger than in the straight nozzle, or they have increased the angle of the supply holes. These changes, as a rule, have made the angle nozzles now on the market of slightly larger capacity than are the straight nozzles put out under the same name.

* Same nozzle in every respect other than that the directing disc has been turned over.

TABLE 16.—Influence of a 45-Degree Angle on the Rate of Discharge.

NOZZLE	Diameter of Orifice in mm.	Discharge in Liters per Hour, 50 lbs. Pressure	Difference in Liters
Tiger Strainer	1.2 (45-degree angle)	54.3	
Tiger Strainer	1.2 (straight)	55.3	1.0
Tiger Strainer	1.6 (45-degree angle)	74.4	
Tiger Strainer	1.6 (straight)	77.4	3.0
Tiger Strainer	2.0 (45-degree angle)	95.2	
Tiger Strainer	2.0 (straight)	98.6	3.4

MINOR FACTORS INFLUENCING THE RATE OF DISCHARGE

Faulty outlet orifices were found to exert a very great influence on the rate of discharge, depending on the shape of the orifice as to whether the capacity was increased or not. Oblong orifices were found to decrease the rate of discharge over that of a perfectly round orifice by as much as 7.5 percent in the case of the eddy-chamber nozzles.

Burrs, small irregularities, or projections were frequently found in the orifices. These exerted a marked influence on the rate of discharge, depending on their size and shape. Some of the burrs would soon wear out and the orifices become round, but in several cases the metal around the burr seemed to wear instead. These small defects would often cause the spray to be unevenly distributed and often were the cause of the nozzle's dripping.

The orifices in some nozzles were punched and a few instances were noted where the metal surrounding the orifice projected out beyond the plane of the disc. In such cases a small difference was observed in the rate of discharge, depending on the way the disc was placed in the nozzle and the amount of the projection. When the extended portion was placed so as to face inward a decrease in the rate of discharge was secured. But when the disc was reversed so that the extended portion was facing outward an increase was obtained. This may at first appear to the reader as somewhat contradictory to the results obtained on the influence of thickness of the disc. This, however, is not true, as the results are in accord with those that have been obtained from orifices of much larger size (for more information see texts on hydraulics). The reason for this may be readily seen from a study of Fig. 16, which diagrammatically shows that when the projection around the orifice extends down into the eddy-chamber the outward passage of the material is interfered with. The opposite is true when the projection extends outward, the rounding of the corners in this case assisting in the discharge of the spray material.

A few of the nozzles studied have a strainer made of perforated brass and placed just in the rear of the directing disc to catch any undissolved spray material or foreign bodies which might be in suspension. This strainer was found to reduce the rate of discharge as would be expected, by increasing friction, but the effect is slight, being only noticeable. Sediment would collect on the strainer and reduce the rate of discharge, but nozzle clogging would be largely prevented, so that on the whole a strainer seems to be a desirable feature.

DEFECTS DUE TO POOR WORKMANSHIP

A few of the nozzles had defects which could readily be overcome. Thin walls of the nozzles were found to become easily distorted and would leak and become a source of great annoyance as well as reduce the efficiency of the nozzle. Caps made of too thin material would split and thus necessitate new ones. Orifices which were not drilled in the center of the disc were occasionally found and these distorted the discharge.

A very great variation in the machining of the parts, and of the final finish of the nozzles was observed and it was found that the nozzle which had the best finish and the most careful workmanship gave the least trouble in operating. These nozzles were as a rule made by the manufacturers who made spray machinery and accessories their main business, and not a side line.

In working with nozzles made of brass, aluminum, or some alloy it was noticed that nozzles made of aluminum as a rule gave more trouble in operating than did the others. This was due to poorer threads and finish, which caused poorer connections and leakage; some nozzles made of aluminum, however, were as satisfactory as the best of those made of brass and in addition were lighter in weight. Several nozzles made of brass could be lightened by reducing the amount of metal used at points where unnecessary, and would still be strong enough to give excellent service.

SUMMARY OF FACTORS INFLUENCING THE RATE OF DISCHARGE

An increase in the area of the outlet orifice gives a greater rate of discharge. The increase per unit of area was found to vary inversely with the area of the orifice. In other words, as the area of the orifice was increased there was not a corresponding increase in the rate of discharge.

An increase in pressure results in a greater rate of discharge. No general rule can be given for the increase for all nozzles except as the pressure is doubled the discharge is greater by 1.4 times.

In most cases a deeper eddy-chamber increases the rate of discharge which varies with the size of the outlet orifice. Exceptions were found where a deeper eddy-chamber reduced the rate of discharge to a certain point and then an increase began to show.

Widening the eddy-chamber was found to increase only slightly the rate of discharge, the rate of increase varying inversely with the size of the outlet orifice.

Within certain limits, the greater the area of the supply holes in the directing disc the greater the rate of discharge.

A supply hole placed in the center of the directing disc was found to have much more influence on the rate of discharge than does a corresponding area located at the outer edge.

An increase in the angle of the supply holes in the directing disc gave a greater rate of discharge, the increase varying with the size of the outlet orifice.

Placing a post on the center of the directing disc just under the outlet orifice increased the rate of discharge.

A thick discharge disc diminished the capacity of the nozzle.

An angle on the nozzle, or a strainer just behind the directing disc was found to reduce the rate of discharge by increasing friction.

Burrs in the outlet orifices, or orifices that were not perfectly smooth and round, greatly influenced the rate of discharge, the amount depending on the imperfection.

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DESCRIPTION AND CAPACITY OF NOZZ

NAME OF NOZZLE	MANUFACTURER	Diameter of Orifice	Thickness of Disc at Side	Diameter of Side-chamber	Inside Diameter of Water-chamber	Depth of Side-chamber	Thickness of Bearing Disc	DIS
Maid of the Mist	H. L. Hurst Mfg Co	1.6	.9	19.1	11.6	3.2	2.2	2
Eureka	Deming Co	1.7	1.5	16.0	13.2	4.8	3.5	2
Lenox	Dravo Mfg Co	1.4	.6	11.2	11.2	6.3	2.7	3
Cyclone (Side Outlet)	F. E. Myers & Bro	1.3	.5	11.5	6.1	3.0	0	1
Sprinkler	F. E. Myers & Bro	1.3	0	0	10.5	0	0	0
Cuba	F. E. Myers & Bro	1.4	1.2	0	11.1	0	0	0
Calla	F. E. Myers & Bro	2.3	1.3	0	13.1	0	0	0
Calla	F. E. Myers & Bro	4.0	1.3	0	13.1	0	0	0
Imperial	F. E. Myers & Bro	1.2	.3	10.0	7.0	2.6	4.7	1
Fog (Angle)	Hudson & Thurber Co	1.8	.7	17.7	17.7	3.5	4.5	2
Fog (Angle)	Hudson & Thurber Co	1.6	.7	17.7	17.7	3.6	4.5	3
Friend Angle	Friend Mfg Co	2.8	.5	25.6	25.6	2.0	2.5	3
Friend Angle	Friend Mfg Co	2.3	.5	25.6	25.6	2.0	2.5	3
Friend Angle	Friend Mfg Co	2.1	.5	25.6	25.6	3.2	2.5	3
Friend Angle	Friend Mfg Co	2.0	.5	25.6	25.6	3.2	2.5	3
Friend Regular	Friend Mfg Co	2.3	.5	25.6	25.6	3.2	2.5	3
Friend Regular	Friend Mfg Co	2.1	.5	25.6	25.6	3.2	2.5	3
Friend Cobra	Friend Mfg Co	2.8	.5	25.6	25.6	3.2	2.5	3
Friend Cobra	Friend Mfg Co	2.3	.5	25.6	25.6	3.2	2.5	3
Friend Cobra	Friend Mfg Co	2.1	.5	25.6	25.6	3.2	2.5	3
Schmidtle	Niagara Sprayer Co	2.3	.5	12.9	13.0	2.9	7.5	4
Schmidtle	Niagara Sprayer Co	2.3	.5	12.9	13.0	2.9	7.5	4
Tiger Strainer Angle	Field Force Pump Co	1.8	.5	22.0	22.0	3.0	3.3	2
Tiger Strainer Angle	Field Force Pump Co	1.6	.5	22.0	22.0	3.0	3.3	2
Tiger Strainer Angle	Field Force Pump Co	2.0	.5	22.0	22.0	3.0	3.3	2
Tiger Strainer	Field Force Pump Co	1.6	.5	22.0	22.0	3.0	3.3	2
Tiger Strainer	Field Force Pump Co	1.6	.5	22.0	22.0	3.0	3.3	2
Tiger Strainer	Field Force Pump Co	2.0	.5	22.0	22.0	3.0	3.3	2
Iron Age	Empire Mfg Co	1.8	.8	18.6	18.7	4.0	4.1	2
Iron Age	Empire Mfg Co	2.0	.8	18.6	18.7	4.0	4.1	2
Progress	Gaston Mfg Co	2.0	1.5	11.3	11.3	4.5	2.5	3
New Eclipse	Morrill & Morley Mfg	2.0	.9	25.0	25.0	3.5	6.0	2
New Eclipse	Morrill & Morley	2.0	.9	21.0	25.0	3.5	6.0	2
Cyclone (Ext.)	F. E. Myers & Bro	1.3	.5	11.5	6.1	3.0	0	1
Myers Way	F. E. Myers & Bro	2.5	0	0	0	0	0	1
Master Spray	Crowe Specialty Co	2.0	.9	16.0	16.0	5.5	4.5	2
Master Sprayer	Crowe Specialty Co	2.0	.9	16.0	16.0	5.5	4.5	2
Sprayist	Deming Co	1.2	.9	22.0	22.0	3.1	3.7	2
Sprayist	Deming Co	1.0	.9	22.0	22.0	3.1	3.7	2
Sprayist	Deming Co	2.0	.9	22.0	22.0	3.1	3.7	2
Simplex	Deming Co	1.6	.9	17.0	17.0	3.0	4.0	2
Simplex	Deming Co	2.0	.9	17.0	17.0	3.0	4.0	2
Acme	Deming Co	2.1	1.6	11.5	11.5	5.0	4.7	2
Acme	Deming Co	2.3	1.6	11.5	11.5	5.0	4.7	2
Atomic	E. C. Brown Co	1.3	.6	26.1	28.2	2.8	4.6	3
Atomic	E. C. Brown Co	1.6	.6	26.1	28.2	2.8	4.6	3
Atomic	E. C. Brown Co	1.9	.6	26.1	28.2	2.8	4.6	3
Hilliard	Hardie Mfg Co	2.0	0	0	0	0	0	1
Vapo	Hardie Mfg Co	1.9	1.7	22.0	22.0	3.8	3.2	2
Cyclone	Hardie Mfg Co	1.6	1.2	9.6	9.6	6.0	1.1	2
Auto Spray	E. C. Brown & Co	1.6	$\frac{3}{4}$	21.0	25.0	3.2	3.5	2
Large Disc (Angle)	Hayes Pump & Pl. Co	1.5	.5	16.0	16.0	3.2	3.2	2
Large Disc (Angle)	Hayes Pump & Pl. Co	1.8	.5	16.0	16.0	3.2	3.2	2
Large Disc St	Hayes Pump & Pl. Co	1.5	.5	16.0	16.0	3.2	3.2	2
Large Disc St	Hayes Pump & Pl. Co	1.8	.5	16.0	16.0	3.2	3.2	2
Bordeaux	Hardie Mfg Co	2.3	0	0	0	0	0	1
Large Disc Sol Ang	Hayes Pump & Pl. Co	1.4	1.0	19.0	16.0	3.2	3.2	2
Large Disc Sol Ang	Hayes Pump & Pl. Co	1.6	1.0	19.0	16.0	3.2	3.2	2
Large Disc Sol St	Hayes Pump & Pl. Co	1.4	1.0	19.0	16.0	3.2	3.2	2
Large Disc Sol St	Hayes Pump & Pl. Co	1.6	1.0	19.0	16.0	3.2	3.2	2
Eastern Bordeaux	Hayes Pump & Pl. Co	2.5	0	0	0	0	0	1
Western Bordeaux	Hayes Pump & Pl. Co	3.0	0	0	0	0	0	1
Spraymaster Fig 54	Spraymaster Co	1.6	.9	22.8	22.5	3.2	4.0	3
Spraymaster Fig 102	Spraymaster Co	2.0	.9	22.8	22.5	3.2	4.0	3
Painting Nozzle	Spraymaster Co	1.5	.9	19.9	7.5	5.0	0	2
Fulcrum Nozzle	Spraymaster Co	1.0	.9	12.7	7.5	5.0	0	2
Fog Angle	Brandt Mfg Co	1.6	.7	17.7	17.7	3.5	4.5	2
Fog Angle	Brandt Mfg Co	1.6	.7	17.7	17.7	3.5	4.5	2
Fog Straight	Brandt Mfg Co	1.6	.7	17.7	17.7	3.5	4.5	2
Fog Straight	Brandt Mfg Co	1.6	.7	17.7	17.7	3.5	4.5	2
Long Distance	Dean Spray Pump Co	1.6	2.0	11.5	11.5	8.0	0	1
Vermorel	Dean Spray Pump Co	1.5	2.5	13.5	8.5	8.0	0	1
Whirlpool	Dean Spray Pump Co	1.4	1.2	20.7	20.7	3.3	8.0	3
Rain Bird	Dean Spray Pump Co	2.5	1.0	22.3	22.3	3.2	5.0	3
Vermorel Dayton	Dayton Mfg Co	2.0	.6	.7	10.3	6.0	0	1
Vermorel Dayton	Dayton Mfg Co	2.5	.6	.7	10.3	6.0	0	1
Power	F. E. Myers & Bro	1.3	.4	12.0	10.0	2.5	3.2	2
Power	F. E. Myers & Bro	2.0	.6	18.0	16.0	2.5	3.2	2
Imperial	F. E. Myers & Bro	2.0	1.0	10.2	9.0	2.3	4.5	1
Dowey	Wm. Stahl Mfg Co	3.2	1.0	11.8	8.2	5.0	1.0	2
Minny M	Gould Mfg Co	1.3	1.2	23.0	23.0	3.2	3.2	3
Minny Jr	Gould Mfg Co	2.5	.9	22.0	22.0	3.2	3.2	3
Minny Large	Gould Mfg Co	1.2	.9	22.0	22.0	3.2	3.2	3
Minny Large	Gould Mfg Co	1.4	.9	22.0	22.0	3.2	3.2	3
Vermorel	F. E. Myers & Bro	1.2	.6	10.1	7.5	5.1	0	1
Vermorel	F. E. Myers & Bro	1.3	.6	10.1	7.5	5.1	0	1
Regular Cap	Hudson & Thurber Co	2.0	2.0	17.7	17.7	3.5	4.5	2
Graduating Vermorel	F. E. Myers & Bro	1.3	.5	9.4	7.5	3.0	0	1
Graduating Vermorel	F. E. Myers & Bro	1.7	.5	9.4	7.5	3.0	0	1
Small Steel Nozzle	Gould Mfg Co	1.4	.8	12.0	8.6	10.0	0	1
Calla	Morrill & Morley	1.2	0	0	0	0	0	0
Calla	Morrill & Morley	1.4	1.2	0	0	0	0	0
Calla	Morrill & Morley	1.2	1.8	0	0	0	0	0
Vermorel	Morrill & Morley	1.8	1.4	20.0	15.5	27	10.1	2
Bordeaux	Morrill & Morley	2.5	0	0	0	0	0	1
Eveball	Blue Brass Works	1.5	1.6	15.9	15.9	0.0	6.5	1
Vermorel	Deming Co	1.7	1.6	10.7	12.8	8.0	3.2	2
Demorel	Deming Co	2.2	1.2	10.7	12.8	8.0	3.2	2
Bordeaux	Deming Co	2.5	0	0	0	0	0	1
Vermorel	Hardie Mfg Co	1.8	1.5	9.5	9.5	4.8	1.1	2
Vermorel	Deming Co	1.6	.3	10.5	13.0	8.0	2.3	2
Vermorel	Deming Co	2.5	.3	10.5	13.0	8.0	2.3	2
Vermorel	E. C. Brown & Co	1.8	.5	8.0	9.0	13.5	0.0	1
Non Clog Atomic	E. C. Brown & Co	1.3	.5	20.7	26.1	2.8	4.6	3
Non Clog Atomic	E. C. Brown & Co	1.6	.5	26.1	28.2	3.3	7.0	1
Non Clog Atomic	E. C. Brown & Co	1.9	.5	26.1	28.2	3.3	7.0	1
Non Clog Atomic	E. C. Brown & Co	1.6	.5	26.1	28.2	3.3	7.0	1
Non Clog Atomic	E. C. Brown & Co	2.0	.5	26.1	28.2	3.3	7.0	1
Non Clog Atomic	E. C. Brown & Co	2.2	.5	26.1	28.2	3.3	7.0	1
Non Clog Atomic	E. C. Brown & Co	2.5	.5	26.1	28.2	3.3	7.0	1
Non Clog Atomic	E. C. Brown & Co	2.8	.5	26.1	28.2	3.3	7.0	1
Non Clog Atomic	E. C. Brown & Co	3.2	.5	26.1	28.2	3.3	7.0	1
Non Clog Atomic	E. C. Brown & Co	3.5	.5	26.1	28.2	3.3	7.0	1
Da Spray	E. C. Brown & Co	1.4	.5	20.7	14.0	7.8	0	1
Special Vermorel	Field Force Pump Co	1.6	.3	11.1	9.1	14.0	0	1
Special Vermorel	Field Force Pump Co	1.8	.3	11.1	9.1	14.0	0	1
Vermorel	Field Force Pump Co	1.5	.4	10.5	8.8	13.6	0	1
Vermorel	Field Force Pump Co	1.6	.5	10.5	8.8	13.6	0	1
Vapo Mist	Field Force Pump Co	1.2	.5	11.5	9.5	6.0	0	2
Vapo Mist	Field Force Pump Co	1.6	.5	11.9	9.5	6.3	0	2
6 in 1 Auto Any (Disc)	Gilford Mfg Co	1.0	.5	20.0	20.0	4.5	3	2
6 in 1 Auto Any (Disc)	Gilford Mfg Co	1.3	.5	20.0	20.0	4.5	3	2
6 in 1 Auto Any (Disc)	Gilford Mfg Co	2.5	.5	20.0	20.0	4.5	3	2
6 in 1 Auto Any (Disc)	Gilford Mfg Co	2.5	.5	20.0	20.0	4.5	3	2
Vermorel	Spraymaster Co	1.6	.9	21.3	13.7	6.8	1	2
Lathan Fig 107	Lathan & Co	2.7	1.6	10.6	12.6	10.0	0	1
Clipper	Dean Spray Pump Co	2.5	0	0	0	0	0	1
Little Cavalier	Lathan & Co	1.2	.5	10.0	10.0	7.0	1	1
Lathan Fig 101	Lathan & Co	1.5	1.0	10.0	13.0	10.0	0	1
Ideal	Brandt Mfg Co	1.6	.8	8.8	10.1	5.0	1.6	2
Perfection	Hudson & Thurber	1.6	.9	13.1	13.1	4.0	1.2	2
Far-Near Nozzle	Far-Near Nozzle Co	2.6	1.2	24.9	28.5	4.0	3.2	3
Far-Near Nozzle	Far-Near Nozzle Co	2.6	1.2	24.9	28.5	4.0	3.2	3
Far-Near Nozzle	Far-Near Nozzle Co	3.0	1.2	24.9	28.5	4.0	3.2	3
Far-Near Nozzle	Far-Near Nozzle Co	3.6	1.2	24.9	28.5	4.0	3.2	3
Sulphur	Woodth & Littig	1.9	.7	$\frac{3}{4}$	.7	.7	1	2
San Jose	Woodth & Littig	.7	.2	0	.7	.7	1	2
Power with Diaphragm	F. E. Myers & Bro	2.0	1.8	13.3	15.4	5.0	0	2

*Measurements in millimeters. Discharge in liters, at 7 weight in grams.

AND CAPACITY OF NOZZ

SUPPLY HOSE		Outlet		Angle of Supply Hose	CLASS	PER HOUR		Weight
Quarter	No.	Diameter				Discharge, at 100 lbs. Pressure	Discharge, 100 lbs. Pressure	
0	0	0		45	Self cleaner	117.3	116.6	50
0	0	0		0	Cap	102.9	120.6	40
0	0	0		75	Cap	87.6	122.0	125
0	0	0		0	Cyclone	53.6	71.1	64
0	0	0		—	Cap	266.3	402.2	29
0	0	0		—	Solid Stream	318.9	294.2	76
0	0	0		—	Solid Stream	464.8	427.2	76
0	0	0		—	Solid Stream	765.9	1110.0	76
0	0	0		20	Cap	89.4	137.0	25
0	0	0		10–	Disc	85.2	93.2	35
0	1	1.6		10–	Disc	132.2	199.5	81
0	0	0		45	Disc	167.8	230.3	104
0	0	0		45	Disc	264.2	364.6	104
0	0	0		45	Disc	317.1	460.6	104
0	0	0		35	Disc	193.6	203.9	83
0	0	0		35	Disc	220.7	313.6	83
0	0	0		35	Disc	266.7	369.9	83
0	0	0		45	Disc	195.5	231.6	88
0	0	0		35	Disc	232.9	442.4	88
0	0	0		45	Disc	262.2	387.6	88
0	0	0		0	Cyclone	53.6	71.1	64
0	0	0		7	Solid Stream	17406.33	245.84	107
0	0	0		45	Disc	209.4	264.6	63
0	0	0		45	Disc	307.8	438.4	65
0	0	0		45	Disc	53.1	73.6	100
0	0	0		45	Disc	87.3	118.7	100
0	0	0		45	Disc	173.2	250.0	100
0	0	0		45	Disc	124.1	171.6	74
0	0	0		45	Disc	162.0	226.6	74
0	0	0		45	Disc	148.8	226.6	52
0	0	0		60	Cap	152.4	247.8	32
0	0	0		45	Disc	45.6	64.8	97
0	0	0		60	Disc	93.9	119.6	97
0	0	0		60	Disc	130.2	190.2	97
0	0	0		30	Bordeaux	424.5	567.4	52
0	0	0		45	Disc	87.3	107.7	70
0	0	0		60	Cyclone	148.8	150.0	51
0	0	0		10–	Cap	56.4	79.0	67
0	0	0		35	Disc	166.6	150.0	85
0	0	0		35	Disc	167.5	232.2	85
0	0	0		35	Disc	193.0	194.8	85
0	0	0		35	Disc	141.9	205.5	82
0	0	0		—	Bordeaux	410.3	567.4	104
0	0	0		60	Disc	91.4	112.6	98
0	0	0		60	Disc	134.0	161.0	98
0	0	0		60	Disc	82.3	115.4	95
0	0	0		60	Disc	120.2	183.7	95
0	0	0		60	Self Cleaner	147.5	180.8	55
0	0	0		7	Vermorel	73.5	106.4	87
0	0	0		45	Disc	143.4	194.4	104
0	0	0		45	Disc	273.5	369.6	78
0	0	0		7	Mod Vermorel	137.5	158.2	81
0	0	0		7	Mod Vermorel	121.4	258.8	57
0	0	0		15	Self Cleaner	128.1	200.4	68
0	0	0		15	Self Cleaner	170.2	261.6	68
0	0	0		45	Cap	209.7	287.7	35
0	0	0		7	Cap	209.0	261.0	78
0	0	0		60	Disc	64.5	87.8	94
0	0	0		45	Disc	127.4	179.4	94
0	0	0		60	Disc	99.2	167.4	167
0	0	0		10	Disc	167.1	247.9	165
0	0	0		7	Vermorel	69.7	89.4	81
0	0	0		7	Vermorel	93.3	131.4	87
0	0	0		45	Cap	113.6	158.4	137
0	0	0		7	Mod Vermorel	73.6	106.7	86
0	0	0		10?	Mod Vermorel	87.2	122.4	86
0	0	0		7	Vermorel	54.2	104.9	122
0	0	0		—	Solid Stream	700.3	1030.8	111
0	0	0		—	Solid Stream	737.8	1096.2	111
0	0	0		—	Solid Stream	814.6	1137.0	111
0	0	0		7	Vermorel	134.5	184.6	108
0	0	0		7	Vermorel	93.3	131.4	87
0	0	0		10–	Disc	132.2	175.8	48
0	0	0		30°	Vermorel	102.6	154.2	77
0	0	0		15	Vermorel	137.2	246.6	77
0	0	0		20°	Vermorel	132.7	249.6	175
0	0	0		—	Vermorel	265.7	349.6	175
0	0	0		10?	Vermorel	97.1	114.6	100
0	0	0		7	Vermorel	52.2	123.7	59
0	0	0		7	Vermorel	104.1	216.6	83
0	0	0		7	Vermorel	107.7	147.3	104
0	0	0		15	Disc	160.4	71.0	150
0	0	0		15?	Disc	31.0	69.1	100
0	0	0		15?	Disc	144.1	149.8	150
0	0	0		15?	Disc	138.0	173.6	150
0	0	0		15?	Disc	134.1	187.9	150
0	0	0		15?	Disc	117.2	151.9	150
0	0	0		15?	Disc	155.7	221.4	150
0	0	0		15?	Disc	213.7	310.6	150
0	0	0		15?	Disc	31.0	69.1	100
0	0	0		7	Vermorel	88.1	128.2	122
0	0	0		7	Vermorel	71.3	114.6	77
0	0	0		7	Vermorel	126.2	187.6	77
0	0	0		7	Vermorel	84.6	122.4	179
0	0	0		7	Vermorel	120.2	182.4	179
0	0	0		30°	Self Cleaner	77.3	104.5	116
0	0	0		30°	Self Cleaner	137.4	199.8	116
0	0	0		10–	Disc	164.1	226.6	136
0	0	0		10–	Disc	166.8	245.1	136
0	0	0		10–	Disc	164.8	247.5	136
0	0	0		10–	Disc	147.8	240.3	176
0	0	0		7	Mod Vermorel	97.4	122.4	80
0	0	0		7	Vermorel	134.1	165.3	43
0	0	0		45	Bordeaux	462.4	577.2	140
0	0	0		7	Solid Stream	169.3	226.4	53
0	0	0		7	Self Cleaner	79.2	105.8	46
0	0	0		—	Cap	56.7	78.8	140
0	0	0		10–	Cap	71 $\frac{3}{4}$ $\frac{1}{16}$	124.4 $\frac{1}{16}$	107
0	0	0		10–	Disc	115.0	145.4	94
0	0	0		45	Disc	230.9	303.6	84
0	0	0		45	Disc	220.2	321.8	84
0	0	0		45	Disc	253.6	351.0	84
0	0	0		7	Cyclone	43.6	87.0	72
0	0	0		7	Solid Stream	0.0****	0.0****	107
0	0	0		10–	Self Cleaner	104.4	140.8	107

**Depending on size of slot

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